BULLETIN

OF THE

UNIVERSITY OF WISCONSIN

SCIENCE SERIES

VOLUME 2

(1897–1901)

WILLIAM HERBERT HOBBS, PH. D., Editor

Professor of Mineralogy and Petrology

PUBLISHED BY AUTHORITY OF LAW AND WITH THE APPROVAL OF THE REGENTS OF THE UNIVERSITY

MADISON, WIS.
PUBLISHED BY THE UNIVERSITY
1901

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Democrat Printing Co., Madison.

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PRICE 35 CENTS

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NO. 25.

SCIENCE SERIES, VOL. 2, NO. 1, PP. 1-31.

THE ACTION OF SOLUTIONS ON THE SENSE OF TASTE

BY

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Assistant Professor of Physical Chemistry.

Published bi-monthly by authority of law with the approval of the Regents of the University and entered at the post office at Madison as second-class matter

MADISON, WISCONSIN
SEPTEMBER, 1898

Bulletin of the University of Wisconsin.

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MADISON, WIS.
JULY, 1898

THE ACTION OF SOLUTIONS ON THE SENSE OF TASTE.[1]

Introduction.

In order to be capable of affecting the sense of taste a substance must be soluble to a certain extent in the saliva, which is, in most cases at least, the same as saying that it must be soluble in water. Substances that are practically insoluble can when introduced into the mouth produce only sensations of temperature and of touch. The fact that a substance is soluble in water is not of itself sufficient, however, to enable it to cause sensations of taste, for there are many substances that are quite soluble in water and yet their solutions possess very little or no taste. It is evident that the effect of a solution on the sense of taste depends upon the concentration of the solution, the chemical nature of the dissolved substances, and the conditions in which the latter exist in the solution.

Investigations on the subject of solutions have been vigorously pushed during the last ten years by workers in the field of physical chemistry, and as a result of their labors we have today a far better understanding of the condition in which a substance exists when dissolved than ever before. Indeed, van't Hoff's[1] theory of solutions and Arrhenius'[2] theory of electrolytic dissociation have practically solved the mystery that has heretofore engrossed the whole subject of solutions.

Since substances must be dissolved in order to be tasted, and since the taste of a solution depends upon the nature of the dissolved substance and its molecular condition when in solution,

[1]Read before the Wisconsin Academy of Sciences, Arts, and Letters at its meeting at Milwaukee, December, 1897.
[2]Zeitschr. f. physik. Chem. 1, 481, 1887.
[3]Ibidem, 1, 631, 1887.

it was thought that a systematic study of the effect of solutions on the sense of taste, pursued in the light of the knowledge that has in recent years been gathered concerning the subject of solutions, would more clearly define the nature of the substances that produce certain tastes and possibly also indicate the mode of action by means of which these substances cause the sensations of taste. The present investigation is an attempt to study the effect of solutions on the sense of taste in the light of the modern theories of the nature of solutions.

The Nature of Aqueous Solutions.

Aqueous solutions may be divided into two classes, those that are practically non-conductors of electricity and those that conduct electricity readily. The former are generally termed non-electrolytes and the latter electrolytes. The aqueous solutions that practically do not conduct electricity are those of substances that possess neither acid, basic, nor salt-like character, or at least they possess these characteristics only to a slight degree. Into this category belong, for example, solutions of the mono- and polyatomic alcohols, the sugars, the esters, very weak acids and bases, colloidal substances, and other compounds generally spoken of as neutral[1] substances. The solutions that conduct electricity readily are those of compounds of pronounced acid, basic, or salt-like character. This class includes solutions of all the acids, bases, and salts except some very weak acids and bases and the salts formed by their combination.

Measurements of the osmotic pressure, the lowering of the freezing point, and the elevation of the boiling point of solutions of non-electrolytes have shown that generally the dissolved substances contained in these solutions exist in the simple molecular condition that is expressed by their chemical formulæ as usually written; in other words, the molecular weight of these substances when in the dissolved condition is that which is generally ascribed to them. When it is possible to find the molecular weight of a non-electrolyte by a vapor density determination as

[1]The term neutral substances as used here does not include salts.

well as from the osmotic pressure, the freezing point, or the boiling point of its solution, the results are generally identical. Instances where double or even more complex molecules are formed when substances are dissolved in water are known, and yet these are perhaps not much more common than cases of polymerization in the gaseous state. The analogy that exists between gases and solutions of non-electrolytes is almost perfect. This appears clearly when we regard the statement of Avogadro —equal volumes of all gases under the same conditions of temperature and pressure contain an equal number of molecules— in conjunction with this statement modified through the work of van't Hoff so as to apply to solutions,—equal volumes of solutions having the same temperature and the same osmotic pressure contain an equal number of molecules, which number is identical with that contained in a gas having the same volume and temperature as the solution and a pressure equal to the osmotic pressure of the latter.

The solutions that conduct electricity on the other hand are different in character. From what has been said, it is clear that these solutions are such as contain the ordinary salts, acids, and bases. These substances do not exist in aqueous solutions in the molecular condition represented by their chemical formulæ as ordinarily written. The osmotic pressure, the lowering of the freezing-point, and the elevation of the boiling-point of these solutions are all greater than they would be if the substances when in solution possessed the molecular weight indicated by the usual formulæ. According to the theory of Arrhenius these substances exist in solution in a partially dissociated state; this explains the peculiar behavior of these solutions as compared with those of non-electrolytes. The degree or extent of this dissociation depends on the nature of the dissolved substance and the concentration of the solution. Theoretically the dissociation is complete only at infinite dilution; many substances, however, are so strongly dissociated when dissolved in water that dissociation is practically complete at finite dilutions. The part-molecules into which the dissolved molecules are dissociated are

termed *ions*. These ions migrate through the solution under the influence of the electric current, whence their name. The conduction of electricity by the solution depends upon the presence and the movements of the ions. Those ions that travel toward the negative pole are considered as charged with positive electricity and are termed cathions, while those that move toward the positive pole are called anions and are charged with negative electricity. The number of cathions in a solution is always equivalent to the number of anions present, so that electrical neutrality of the solution is preserved. Thus in the case of sodium chloride the ions are Na and Cl, and any solution of this salt contains these ions together with a certain amount of undissociated Na Cl, the relative quantities of dissociated and undissociated salt depending on the concentration of the solution. Similarly solutions of hydrochloric acid contain the ions H and Cl and undissociated molecules of HCl.

It would seem at first that matters become more complicated by thus considering the solutions just mentioned; while this is true in some cases, namely when concentrated solutions are under consideration, yet in dilute solutions where dissociation is nearly complete things appear more simple. Thus in very dilute solutions hydrochloric acid and sodium chloride are practically completely dissociated, and the dissolved substances that these solutions contain are consequently the ions $\overset{+}{H}$ and $\overset{-}{Cl}$ in the former and $\overset{+}{Na}$ and $\overset{-}{Cl}$ in the latter. The ions are to be regarded as distinct and separate substances subject, however, to the law that the solution contains as many positive as negative ions. The ions are furthermore not identical with ordinary hydrogen, chlorine and metallic sodium respectively, for they differ from these in the amount of energy they contain. It is necessary to supply these ions with additional energy in order to change them from the ionic condition to the ordinary state. This can be done, for example, by electrolyzing hydrochloric acid or sodium chloride.

Two dilute solutions containing chemically equivalent quan-

tities of hydrochloric acid and sodium chloride are alike in that they contain chlorine ions in the same concentration, while they differ in that the former contains hydrogen ions and the latter sodium ions. It has always been regarded as axiomatic that the properties of a solution are determined by what the solution contains. Hence the differences in the properties of the dilute solutions of hydrochloric acid and common salt are simply to be ascribed to the different effects of the H ions and the Na ions, the Cl ions being common to both solutions. Now it happens that a solution of hydrochloric acid still has a very pronounced taste at a degree of dilution at which a common salt solution containing a chemically equivalent quantity is perfectly tasteless. It follows, therefore, that the taste of such a dilute solution of hydrochloric acid is simply due to the hydrogen ions it contains. The dilute solution of hydrochloric acid gives one the sensation of sour, and consequently hydrogen ions cause sour taste. The latter statement will be more fully established below.

From what has been stated concerning the nature of aqueous solutions, it follows that in the case of solutions of non-electrolytes we have simply to investigate the taste of the dissolved molecules and to seek a relation between the chemical nature of these and the sensations that they cause; while in the case of solutions of electrolytes, we shall have to consider the taste of both the undissociated molecules and the ions present, trying to discover if possible a connection between the gustatory sensations that these create and the other properties that they possess. It is clear that the study of the second class of solutions may be much simplified by working with dilute solutions. By so doing the taste of individual ions may even be determined as indicated in the preceding paragraph.

The Sense of Taste.

The organs of the sense of taste are located in the epithelium of the upper surface of the tongue and possibly also in the lining of other parts of the mouth cavity. The nerves of the

tongue run into papillæ, of which the so-called circumvallate, on the posterior part of the tongue's surface have an especially rich nerve supply. On these are the terminal organs of taste consisting of peculiar bodies, the so-called taste-bulbs or taste-buds, discovered by Schwalbe and Lovén in 1867. These taste-bulbs, which are minute bodies, oval in shape, are lodged in the epithelium covering the side of the papilla. Each consists of two sets of cells. On the outside are a number of flat, fusiform, nucleated cells known as supporting or protective cells; these are bent like the staves of a barrel and arranged side by side so as to form a bulb-shaped body, having an aperture at the apex known as the gustatory pore. The inside of the taste-bulb contains five to ten so-called taste-cells, which are pointed at the end next to the gustatory pore and branched at the other end where they are probably connected with nerve fibres. According to Ranvier[1] supporting cells are also found in the interior of the taste-bulbs, the taste-cells being found interspersed between these. Taste-bulbs occur also on other papillæ of the tongue, and it is possible that simpler structures consisting of fewer or even single taste-cells exist where no taste-bulbs are located, for it is known that taste does exist on parts of the tongue where no taste-bulbs have been found. The tip, edges, and back of the tongue are sensitive to taste, while the middle is devoid of taste. The organs of taste are similar in construction to those of smell.

The above is a brief statement of what is generally given concerning the organs of taste in standard works[2] on physiology, histology, and physiological psychology. Retzius,[3] who has made an extensive study of the nerve endings of the various organs of the special senses, states that he has been unable to find nerve-fibres connecting the so-called taste-cells with the nerve underneath, that the lower terminus of the taste-cells is in many

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[1] Traité Technique d'Histologie, p. 946.

[2] See for example Martin, The Human Body; Ranvier, Traité d Histologie; Wundt, Grundzüge der physiologischen Psychologie.

[3] Biologische Untersuchungen IV., p. 24.

cases foot-shaped, and that it is highly improbable that they are connected directly with underlying nerves. He finds that nerve-fibres ramify between the cells throughout the entire interior of the taste-bulbs. These nerve-fibres, which he terms the intrabulbular nerves, are a continuation of underlying nerves; they traverse the taste-bulb in a general vertical direction, running out into free ends that are located in many cases near the gustatory pore, in other cases more remote from that opening. Retzius thinks the so-called taste-cells are true epithelial cells; he regards them as "secondary sense cells," similar to the "hair cells" of the sense of hearing. Retzius then finds more analogy between the organs of taste and hearing than between those of taste and smell. Speaking of the sense of taste, he says:[1]

"Es sind meiner Ansicht nach im Geschmacksorgan keine wahren Sinnesnervenzellen vorhanden. Die Nervenzellen des Geschmacksorgans haben sich ebenfalls, wie im Tastorgan, aus dem Epithel zurückgezogen und liegen in den Ganglien des Geschmacksnerven. Das Geschmacksorgan steht also in morphologisch-phylogenetischer Beziehung auf etwa demselben Standpunkt wie das Tastorgan und gewissermassen das Gehörorgan. Die weit gegen das Centralorgan zurückgetretenen Nervenzellen senden in das peripherische Organ ihren peripherischen Fortsatz, welcher unter starker Verästelung mit frei auslaufenden Spitzen frei und interzellulär im Epithel endigt; in dem Epithel der Geschmackszwiebeln sind indessen eigenthümliche Zellen vorhanden, welche ungefähr, wie die Haarzellen des Gehörorgans, als eine Art secundärer Sinneszellen aufgefasst werden können." According to this view it is of course not difficult to see why certain portions of the tongue are sensitive to taste and yet possess no taste-bulbs.

It is generally accepted that sensations of taste are caused by certain irritations of the nerve terminals,—whether we are to regard the "taste-cells" or the "intracellular nerves" as representing these end-organs is perhaps still an open question, though Retzius appears to have excellent grounds for his opinion. Authorities apparently agree that this irritation of the nerves is due

[1]Loc. Cit., p. 53.

to chemical action upon them. Now in order to get into contact with the end-organs a substance must be in solution. This, however, is not of itself sufficient. To get into the taste-bulb, the mouth of which is always covered with mucous, and to get at the nerve, the dissolved substance must diffuse with a fair degree of readiness; and finally, when it has come into contact with the nerve terminus, it must be capable of acting chemically on the protoplasm of the same, thus causing the irritation that is interpreted as taste. Many substances are tasteless simply because they are insoluble; others, although sufficiently soluble, do not diffuse readily enough to come into contact with the nerve terminus; and still others, which though soluble and sufficiently diffusible, are devoid of taste because they fail to react chemically with the protoplasm of the nerve.

It is evident that for each substance there is a certain minimum amount that must be present in order to cause sufficient irritation at the nerve. This amount will naturally be relatively less in the case of those substances that react more intensely with the protoplasm of the nerve terminus. Again, in the case of those substances that because of very slow diffusion possess but little taste, the solutions must be relatively much stronger in order that sufficient substance may come into contact with the nerve, for the speed of diffusion of a substance is proportional to the difference in concentration that exists between the two layers in contact. No doubt the mechanical action of rubbing the tongue against the palate as we do in tasting aids in bringing the substance to be tasted into contact with the taste-organs. We should, other things being equal, expect a substance that diffuses readily to exert an effect on the end-organs in less concentrated solution than a substance that diffuses more slowly. The electrical conductivity of solutions of electrolytes is dependent upon the number of ions present and the speed with which they move through the solution. From this it is clear that the conductivity of electrolytes and their speed of free diffusion are closely connected, and we should conse-

quently expect to find a relation between the electrical conductivity of solutions and their effect on the end-organs of taste.

When volatile substances are introduced into the mouth, the volatilized portions fill the mouth cavity and also the nasal passages; in the latter they frequently act on the organs of smell, and we are very apt to confound the smell of such substances with their taste. Indeed, it is well known that many volatile substances, which we commonly regard as having a strong taste, in reality have no taste at all, for when the nasal passages are obstructed these substances are without taste. It is clear from this that experiments on the sense of taste are best conducted with substances that are non-volatile.

The sensations of taste are commonly classified as those of sweet, sour, salty, and bitter, to which Wundt[1] adds alkaline and metallic. There can be no doubt, however, that there are very many kinds and shades of taste that are quite distinct and not to be referred to sensations of touch, and that the above classification can claim at best to be only a very rough one. The investigator of this subject is soon struck by the fact that we have so few names to describe the various tastes. It is often very difficult for the subject experimented upon to report in words what taste the substance under consideration has, in spite of the fact that a very definite impression is experienced.

The sense of taste is frequently regarded as rather vague, indefinite and uncertain, probably in part because it is not more definitely localized, and yet, experiments show that it is exceedingly sensitive toward many things, and the fact that it may be cultivated to distinguish very small differences is beyond dispute.

The Method of Experimentation.

Fifteen persons served as subjects to be experimented upon. Thirteen of these were between twenty and thirty years of age; of this number three were ladies. The other two, a lady and a

[1]Grundzüge der physiologischen Pyschologie I., p. 439.

gentleman, were about sixty and sixty-three years old respectively. All were in excellent health and were practically total abstainers from the use of intoxicating liquors and tobacco.

The solutions, which were prepared with distilled water that was practically tasteless, contained chemically equivalent quantities, i. e., they were so-called normal solutions. I chose the solutions of such strength that they would give me distinct impressions of taste, not sufficiently strong, however, to produce in any case lasting disagreeable or painful sensations. A portion of each of these solutions was then diluted with water to one-half its former strength; a portion of each of the solutions thus obtained was again diluted with water to one-half its strength, and so on until a solution was obtained, the taste of which I could not distinguish from distilled water. About 200 cc of each dilution was prepared. The solutions were kept in flasks thoroughly cleaned and steamed; they were labeled in cipher known only to me. This was done because many of the persons tested were conversant with chemical symbols, and it was my purpose to have them entirely ignorant of the contents of the solutions they were tasting, so that they would report the sensations they received without being biased by thoughts as to how the solution ought to taste. The chemicals used were of the chemically pure kind of reliable makers. The distilled water was always used as a check.

The subject was first given an opportunity to thoroughly rinse the mouth with distilled water so as to remove any excess of mucous. Seated with his back toward the table on which were the flasks containing the solutions, the subject took from a porcelain spoon about four cubic centimeters of the solution to be tasted. The individual held this in the mouth for a few moments, being permitted to move the tongue and lips at will so as to spread the liquid over the entire cavity of the mouth, and bring the liquid into more immediate contact with the membranes by friction. The solution was then ejected, the report given, and the mouth generally rinsed with a little distilled water

before another solution was tasted. I had the person sit with his back toward the table on which the flasks stood, for I found it necessary that, in order to get from him an unbiased report, he should not know from which flask I was giving him. In testing as to the relative strength of the taste of several solutions, I could thus give the same solution twice in succession or give simply distilled water without the subject's knowledge. I found that this procedure was quite necessary in many cases in order to obtain reliable results. The distilled water and the solutions were of the same temperature, about 23° C. As my purpose was rather to compare the tastes of different solutions than to find out in each case as accurately as possible the most dilute solution that could still be tasted, I did not deem it necessary to raise the temperature of the liquids to that of the body.

Each person experimented upon was not detained more than half an hour at a time, and the solutions were always given beginning with the weaker and proceeding to the stronger. This was very essential, for preliminary experiments indicated that when a strong solution is first given the effect of it is apt to remain in the mouth and make other tests difficult for the time being or perhaps even impossible. For the same reason, too, all strong solutions that would be apt to leave a prolonged taste in the mouth were either entirely avoided, or given the subject as the last solution to be tested at that sitting. The solutions used were in all cases perfectly odorless unless otherwise stated.

The Taste of Solutions of Electrolytes.

The taste of solutions of electrolytes received attention, first, because these solutions have in many cases very pronounced tastes that render work with them relatively easy; furthermore, when I first began the experiments, it was simply my purpose to investigate the taste of the ions; as the work progressed it took a somewhat wider scope, nevertheless most of the experiments were conducted with solutions of electrolytes.

Sour Taste. As pointed out above the sour taste of acids is

due to the hydrogen ions present.[1] In order to firmly establish this experimentally a $\frac{n}{200}$ hydrochloric acid solution was prepared; this I found to have a very decided acid taste. From this solution $\frac{n}{200}$, $\frac{n}{400}$ and $\frac{n}{800}$ solutions were prepared as before described. On testing the fifteen individuals mentioned, it was found that four of them could detect a difference between the $\frac{n}{800}$ solution and the distilled water, while all of them distinctly tasted the $\frac{n}{400}$ solution. The $\frac{n}{800}$ solution was reported not as sour, but as slightly astringent; the $\frac{n}{400}$ was reported as astringent by the men but by the ladies uniformly as astringent and slightly sour.[2] As at these dilutions the dissociation of the hydrochloric acid is practically complete, and as it requires a much stronger solution of Na Cl than $\frac{n}{400}$ to cause taste, as will be shown below, it is clear that the sour taste is simply due to the effect of the hydrogen ions. I have no doubt that with cultivation of the taste for hydrogen ions, and previous elevation of the temperature of the solutions to that of the body, even more dilute solutions than $\frac{n}{800}$ could be detected by the sense of taste. Indeed, the experiments of Richards[3] confirm this. He shows clearly that fairly accurate titrations of hydrochloric acid can be made using the taste of the solutions to indicate the end of the reaction.

The $\frac{n}{200}$ solution of hydrochloric acid was uniformly reported as sour, as was of course also the $\frac{n}{100}$. Solutions of sulfuric, hydrobromic, and nitric acids equivalent to those of hydrochloric were also prepared, and the subjects were tested with these. The results were the same as with the corresponding solutions of hydrochloric acid. The $\frac{n}{800}$ solutions were reported as astringent by those that could distinguish them from distilled water, $\frac{n}{400}$ were reported as astringent by the men

[1]After the presentation of this paper to the Wisconsin Academy and before it could be published, there appeared an interesting article by T. W. Richards on "The Relation of the Taste of Acids to Their Degree of Dissociation," Amer. Chem. Jour., Feb. 1898. He also expresses the idea that sour taste is caused by hydrogen ions.

[2]On the whole, I found but little difference in the delicacy of the taste of the different persons tested; I had anticipated much greater individual differences than I actually found.

[3]Loc. Cit.

and as astringent and slightly sour by the women, while all found the $\frac{n}{200}$ and $\frac{n}{100}$ solutions distinctly sour. No difference either qualitative or quantitative could be distinguished by these individuals between the solutions of these various acids of equivalent strengths. The electrical conductivity[1] of solutions of these acids shows that in their $\frac{n}{400}$ solutions the compounds are practically completely dissociated, the number of undissociated molecules present at this concentration is then practically nil. It will be shown below that the sodium salts of these acids in $\frac{n}{400}$ solutions, or even much greater concentrations, are tasteless.

In testing solutions of acetic acid it was found that $\frac{n}{200}$ could be tasted as astringent while $\frac{n}{100}$ was reported as sour, though much less so than $\frac{n}{100}$ solution of the other acids mentioned. The electrical conductivity of solutions of acetic acid shows that in $\frac{n}{200}$ and $\frac{n}{100}$ solutions the degrees of dissociation are about 6 per cent. and four per cent. respectively. One would then expect acetic acid solutions to be less sour than equivalent solutions of the strong mineral acids; at the same time, it is apparent that if hydrogen ions can be tasted as astringent in $\frac{n}{800}$ solutions, a $\frac{n}{200}$ solution of acetic acid, which is dissociated only about 6 per cent. and hence with respect to hydrogen ions is $\frac{6}{20000}$ normal, ought to be tasteless. To be $\frac{n}{800}$ with respect to its content in hydrogen ions, a $\frac{n}{200}$ acetic acid solution ought to be dissociated 25 per cent. It is clear then that the $\frac{n}{200}$ solution of acetic acid, being dissociated only about 6 per cent. has a sour taste about four times as strong as it ought to have, assuming that the taste is due simply to the hydrogen ions momentarily present. Richards[2] obtained a similar result; he found that the acetic acid was about one-third as strong as an equivalent solution of hydrochloric acid, though the acetic acid was only dissociated to the extent of one-fourteenth. Richards gives no explanation of this phenomenon, and at the present time I also have none to offer. The further investigation of this point together with that of the

[1]See Ostwald, Allgemeine Chemie **2**, p. 722 et seq., also Landolt u. Börnstein's physikalisch-chemische Tabellen.

[2]Loc. Cit.

interesting question of the taste of acid sodium salts of polybasic acids is contemplated.

The foregoing results and those of Richards show conclusively that hydrogen ions have a sour taste; furthermore, it is clear that in very dilute solutions they produce simply an astringent sensation. The question arises, Is sour taste always due to the presence of hydrogen ions? I am inclined to answer this question in the affirmative, for I know of no substance that has a sour taste which on going into solution in water does not yield hydrogen ions.

With regard to the astringent effects, it seems that in many if not in all cases these can be ascribed to the presence of hydrogen ions in about $\frac{n}{400}$ solution. I was deeply impressed with the fact that many of the subjects tested said that the $\frac{n}{400}$ solutions of the mineral acids tasted like alum. It has been shown[1] that alum solutions contain hydrogen ions in small quantities due to the so-called hydrolytic dissociation of the aluminum sulfate, i. e., to a reaction of this salt with water forming a small amount of sulfuric acid from which in turn by electrolytic dissociation hydrogen ions form. In presence of the sulfate of the alkali metal an acid salt would no doubt form from which, according to previous investigations,[2] hydrogen ions split off rather difficultly. The acid reaction of alum solutions toward indicators is of course further proof of the presence of hydrogen ions. The astringent taste of solutions of ferric salts and their acid reaction toward indicators are well known; these solutions like those of aluminum salts have long been used in medicine because of their astringent properties, which I am inclined to ascribe to the hydrogen ions present due to hydrolytic dissociation. This statement is of course not to be construed as meaning that the other ions and the undissociated molecules present in these solutions do not exert an effect, for

[1]See Long's work on the inversion of sugar by salts, Jour. Amer. Chem. Soc. **18**, Feb. and Aug., 1896.

[2]See Trevor, Zeitschr. f. physik. Chem. **10**, p. 321; Tower, ibid. **18**, p. 17 u. **21**, p. 90; Smith, ibid. **25**, p. 144.

no doubt they do especially in strong solutions, and to these effects the differences of the individual solutions are due.

It is well known that solutions of most of the salts of the heavy metals have acid reactions and that they have an astringent effect upon the membranes of the mouth, besides creating in some cases the so-called metallic taste. The solutions of all of these salts contain hydrogen ions whose presence is caused by hydrolytic dissociation as in the case of the salts of iron and aluminum. To these hydrogen ions the astringent effect of the solutions is very likely to be ascribed in many cases. Salts of stronger acids with the alkalies are not decomposed hydrolytically and do not possess astringent properties. Long[1] used the method of sugar inversion in investigating the hydrolytic decomposition of salt solutions. He employed a polariscope in his work and consequently could test only colorless solutions. The freezing- and boiling-point methods, however, can be used quite as well as the polariscope in this work; although by means of them the observations are perhaps not quite as accurately and readily made. They possess the advantage, however, that they can be used with colored solutions. Experiments along this line have for some time been in progress in this laboratory and the results will soon be ready for publication.

As to the nature of the chemical action of the hydrogen ions on the nerve nothing definite is known, indeed the same must be said of the action of any ingredient on the nerves of taste. It is significant, however, that hydrogen ions can be detected by the sense of taste in very dilute solutions, the limit being in the neighborhood of $\frac{n}{800}$, or one gram of hydrogen ions in 800,000 grams of water. The speed of migration of the hydrogen ion exceeds that of any other ion; it is about one and three-fourths times that of the next fastest ion, the hydroxyl ion. Intimately connected with this is the fact that solutions of strong acids diffuse more rapidly than those of their salts. By virtue of their great mobility, it is clear that hydrogen ions can easily

[1]Loc. Cit.

get at the end organs of taste. It is well known that hydrogen ions in many cases accelerate chemical action, i. e., they have a so-called catalytic effect. Whether it will be found that they accelerate the action that goes on in the nerves or unite with their protoplasm, can not be stated now; it does seem suggestive, however, that the ion which has the least relative mass and by far the greatest mobility can be tasted in more dilute solutions than other substances and causes that peculiar sharp sensation.

Alkaline Taste.—Dilute solutions of caustic alkalies have the characteristic alkaline taste. The effect upon the tongue is very different from that produced by hydrogen ions. In aqueous solutions the caustic alkalies are dissociated into hydroxyl ions and the ions of the metal or basic radical; thus in the case of NaOH the ions are Na and OH, in the case of KOH, K and OH, etc. Solutions of the hydroxides of sodium, potassium and lithium of the strengths $\frac{n}{800}$, $\frac{n}{400}$, $\frac{n}{200}$, and $\frac{n}{100}$ were prepared, and their taste was investigated as in the investigation of the acids. It was found that $\frac{n}{800}$ NaOH could not be distinguished from distilled water; the $\frac{n}{400}$ solution could be tasted very faintly;—the taste was difficult to describe, some calling it a rather stale taste. The $\frac{n}{200}$ solution was reported as alkaline by all, at the same time some also received a slight sensation of bitter from the same. The solution of KOH and LiOH yielded essentially the same results. The persons tested apparently were not able to distinguish any difference either qualitative or quantitative between solutions of equivalent strength of these three alkalies. The alkalinity of a $\frac{n}{200}$ solution of NaOH is plainly recognized by the sense of taste. In this solution the dissociation of the NaOH is practically complete. As a solution of NaCl of equivalent strength is tasteless, as will appear below, it follows that the alkaline taste of the NaOH solution is to be ascribed to the effect of the OH ions. Hydroxyl ions then have the so-called alkaline taste. In stronger solutions caustic alkalies are known to produce nausea. It is probable that this is due to their large content of OH ions, the caustic alkalies being even in fairly concentrated solutions in a relatively highly dissociated state.

It is well known that solutions of salts of strong bases with very weak acids have an alkaline reaction toward indicators. This is due to the fact that these salts are to a certain extent hydrolytically decomposed by the water into free acid and caustic alkali, the latter yielding OH ions by electrolytic dissociation. As examples of salts whose solutions possess alkaline reactions and tastes because of the OH ions due to hydrolytic dissociation may be mentioned the carbonates, silicates, and borates of the alkalies, and the soaps. The fact that the latter in strong solutions produce vomiting is well known; probably this effect is due to the OH ions present in the solutions.

The taste that a dilute solution containing OH ions causes is difficult to describe. Some of the persons tested said it was a soft, smooth sensation quite unlike that produced by other substances. It would seem somewhat peculiar perhaps that the taste of hydroxyl ions, being not sharp like sour or salty tastes, should manifest itself in solutions containing only one gram ion (i. e., 17 grams of OH) in 400 liters. It must be remembered in this connection that hydroxyl ions, like hydrogen ions, are generally speaking very reactive. What the nature of the action of the OH ions on the protoplasm of the nerve is, is not known. The mobility of OH ions is very great (being second only to that of H ions as already pointed out), consequently we should expect them to find little difficulty in reaching the nerve endings.

Water itself is slightly dissociated into hydrogen, and hydroxyl ions. The degree of this dissociation is, however, exceedingly small. Very pure water has been prepared by Kohlrausch, the electrical conductivity of which showed that there were no more than 18 grams of dissociated water present in eleven million liters. It is clear that this is far beyond the limit at which H and OH ions can be detected by the sense of taste. It is not very difficult to obtain distilled water of a specific conductivity of 2×10^{-6} and such water is devoid of taste. If we inquire as to the reason for this, we should agree that the undissociated molecule of water is tasteless because it does not react chemically

with the protoplasm of the nerve; the other alternative, that it does not reach the nervo because of too slow diffusion is here excluded.

Salty Taste.—The taste of common salt is generally given as the type of salty taste. It was found that of the persons tested only three could distinguish a slightly salty taste in $\frac{n}{50}$ solution of sodium chloride, while all recognized $\frac{n}{25}$ as a trifle salty. It requires then a much stronger solution to produce the salty taste than either the sour or the alkaline. In $\frac{n}{50}$ solution Na Cl is dissociated to the extent of about 91 per cent. and in $\frac{n}{25}$ to about 88 per cent. As equivalent solutions of sodium acetate are not salty, possessing hardly any taste, it is clear that the salty taste of the common salt solutions is due to the chlorine ions. The fact that borax solutions of equivalent sodium content are not salty and that many of the individuals tested found difficulty and others could not distinguish between $\frac{n}{25}$ solutions of KCl, LiCl, and NaCl, argues in favor of this view. The taste of the ions of the alkali metals will be discussed later.

Sodium bromide solutions of the strength $\frac{n}{25}$ were found to be distinctly salty by all; a few seemed to taste the $\frac{n}{50}$ solution, but very faintly. This salt is dissociated to about the same extent as the corresponding solutions of sodium chloride. The salty taste of the solutions of Na Br is due to the Br ion. The sense of taste is apparently able to detect this ion in solutions nearly as dilute as the chlorine ion. I found that several persons seemed to detect a qualitative difference between $\frac{n}{25}$ NaCl and NaBr solutions by the sense of taste, others again reported no perceptible difference. Those that did find a difference said that the chloride solution was a little sharper than that of the bromide.

Sodium iodide solutions could be tasted in $\frac{n}{50}$ solutions and more clearly in $\frac{n}{25}$. In neither of these cases was the taste, salty. It takes about a $\frac{n}{6\frac{1}{4}}$ solution to cause the salty taste to appear. The same was observed in case of solutions of potassium iodide, only here the taste of $\frac{n}{50}$ solutions was more marked and rather bitter. The behavior of these solutions will again be

considered below in connection with the taste of cathions. It is evident from the results obtained that iodine ions do not have as salty a taste as do bromine and chlorine ions. The salty taste of the chlorine, bromine, and iodine ions decreases as the atomic weight increases. The mobility of these ions as determined from the conductivity of the respective sodium salts is nearly the same.

In working with sodium nitrate, I found that all the individuals could taste a $\frac{n}{12\frac{1}{2}}$ solution, though very faintly. They found it impossible to describe the taste. The $\frac{n}{6\frac{1}{4}}$ solution was a trifle salty to eight, but they said it was quite a different taste from that of sodium chloride. Of the others, three could not describe the taste, four said it was a smooth taste, and one person said it was more like that of borax than common salt to him. In $\frac{n}{6\frac{1}{4}}$ solutions sodium nitrate is dissociated over eighty per cent. and in $\frac{n}{12\frac{1}{2}}$ about 90 per cent. It follows that neither the Na nor the NO_3 ions have a very pronounced effect on the sense of taste. The slightly salty taste of the $\frac{n}{6\frac{1}{4}}$ solution is probably due to the NO_3 ion, for the sodium ion does not produce such an effect, as is evident from the taste of solutions of sodium acetate. The speed of migration of the sodium ion is about $\frac{1}{7}$ of that of the hydrogen ion, and the speed of the NO_3 ion is about $\frac{1}{5}$ that of the hydrogen ion.

Sodium sulfate was tasted in $\frac{n}{25}$ solution, though not as salty. It was found difficult to describe the taste. Even in $\frac{n}{12\frac{1}{2}}$ solution this substance did not produce a salty taste. In $\frac{n}{6\frac{1}{4}}$ solution a salty taste described by some as slightly bitter was recognized, though all agreed that the "salty taste" was different from that produced by common salt. In $\frac{n}{25}$ solutions $Na_2\,SO_4$ is dissociated about 75 per cent. and in $\frac{n}{6\frac{1}{4}}$ about 62 per cent. The result shows that the SO_4 ion does not have a very pronounced taste. The mobility of the ion $\frac{1}{2}$ SO_4 is about that of the halogen ions mentioned above.

Solutions of sodium acetate of the strengths $\frac{n}{25}$, $\frac{n}{12\frac{1}{2}}$, and $\frac{n}{6\frac{1}{4}}$ were distinctly tasted but in no case reported as salty. The taste was variously described as smooth, sweetish, faintly alka-

line, etc. Even when this salt is taken into the mouth in very concentrated solution the taste is not salty. Indeed, the taste is not pronounced and it is most difficult to describe it in words. From the taste of sodium acetate solutions it follows then, that neither Na ions, CH_2COO ions, nor undissociated molecules of sodium acetate possess a strong taste. The taste of sodium ions is but slight, they seem to produce a smooth sensation that can not be detected in very dilute solutions. This together with the fact that sodium salts are most strongly dissociated admirably adapts the latter for investigating the taste of anions of various kinds. Since sodium ions migrate only $\frac{1}{7}$ as fast as hydrogen ions their rate of diffusion is relatively slow and this may in part account for the fact that they do not affect the sense of taste more. There seems but little room for doubt that in the presence of an ion of pronounced taste, the taste of the sodium ion is completely masked.

The Taste of Cathions.—The tastes of hydrogen and sodium ions have already been discussed in connection with the taste of the anions. To find the taste of a cathion we shall choose a solution of a salt the anion of which has little or no taste at a dilution at which the salt is fairly nearly dissociated and at which the cathion can still be tasted.

The taste of potassium ions is rather bitter and disagreeable. Solutions of the nitrate, sulfate, and acetate of potassium that can be plainly tasted produce, especially on the back of the tongue, a bitter and rather disagreeable taste. The corresponding sodium salts do not produce this effect, and as potassium salts even in fairly strong solution are highly dissociated, this effect is to be ascribed to the action of the potasium ions. Thus the individuals tested could taste KNO_3 solutions that were $\frac{n}{25}$; the report was that the taste of the solution was smooth, alkaline (?). In $\frac{n}{12\frac{1}{2}}$ solution the same taste together with a bitter sensation was reported, while $\frac{n}{6\frac{1}{4}}$ solution was found to be decidedly disagreeable. In $\frac{n}{6\frac{1}{4}}$ and $\frac{n}{12\frac{1}{2}}$ solutions KNO_3 is dissociated about 77 per cent. and 87 per cent. respectively; as the corresponding sodium salts at these concentrations do not pro-

duce this bitter taste, which is characteristic of all potassium salts, it is clearly to be ascribed to the potassium ions. The mobility of potassium ions is about one and one-half that of sodium ions so that their diffusion is more rapid. The taste of potassium ions being fairly pronounced, it is not as readily masked as that of sodium ions. Thus it is possible to distinguish solutions of KCl from NaCl and KI from NaI; the iodine ion not having as strong a salty taste as the chlorine ion, the difference in taste between the potassium and sodium ions comes out fairly distinctly in dilute solutions of the last named salts. Sulfate of potassium solutions have the characteristic bitter, disagreeable taste of the potassium ions; these solutions lack the sharp taste of the NO_3 ions, which we have in strong solutions of KNO_3 and other nitrates when these are applied to the tip of the tongue. Solutions of $KClO_3$ do not have the salty taste of the chlorine ions. The bitter taste of the potassium ion is somewhat masked by the effect of the ClO_3 ion, the latter acts especially on the tip and edges of the tongue creating its own characteristic sharp taste. Solutions of $NaBrO_3$ were incidentally tested in this connection; they have but a slight taste which is not salty. The BrO_3 ion has a taste similar to that of the ClO_3 ion, which would naturally be expected. The tip of the tongue is quite susceptible to irritation by various salts, many of them giving that peculiar sharp or burning sensation, which is different from the taste of hydrogen ions; thus, KI, NaI, NaCl, NH_4Cl, etc., besides the nitrates when applied in strong solutions on the very tip of the tongue cause a burning sensation, which they do not produce on other parts of the organ.

Lithium ions appear to have but little taste. A $\frac{n}{25}$ solutions of Li NO_3 was very difficult to detect by taste; $\frac{n}{12\frac{1}{2}}$ gave a rather alkaline smooth impression, and $\frac{n}{6\frac{1}{4}}$ a sharp taste like a solution of $NaNO_3$ of equivalent concentration. This sharp taste is probably due to the action of the nitrate on the tip of the tongue and is to be ascribed to the action of the NO_3 ion. The mobility of the lithium ion is only a little over one half that of the potassium ion, hence its diffusion is slower,

which would in part account for its less pronounced taste. The taste of magnesium ions is probably bitter as appears from the taste of magnesium sulfate solutions. It takds about $\frac{n}{12\frac{1}{2}}$ to $\frac{n}{6\frac{1}{4}}$ solutions of this salt to produce a distinctly recognizable bitter taste. In the latter concentration the salt is dissociated only about 40 per cent. so that it is an open question as to whether the undissociated molecules of $MgSO_4$ or the Mg ions cause the bitter taste. Magnesium ions very likely have a bitter taste as other solutions in which they occur have this taste; probably the undissociated molecules also have a similar effect. In solutions of $MgCl_2$ we have both the bitter taste of the Mg ions and the salty effect of the Cl ions. The combined effect is such as to make the taste of the solutions of this salt most disagreeable. A solution of $MgCl_2$ that was $\frac{n}{25}$ was recognized as salty but not as bitter, while $\frac{n}{12\frac{1}{2}}$ and $\frac{n}{6\frac{1}{4}}$ solutions produced both the salty and bitter effects, which is what we should expect according to the dissociation theory and the results obtained in case of $MgSO_4$ and NaCl as given above. In $\frac{n}{6\frac{1}{4}}$ solution the degree of dissociation of $MgCl_2$ is about 70 per cent. The mobility of the ion $\frac{1}{2}$ Mg is about the same as that of the lithium ion.

The taste of $Ca(NO_3)_2$ is a trifle sharp in $\frac{n}{12\frac{1}{2}}$ solutions and distinctly bitter in $\frac{n}{6\frac{1}{4}}$. It is a different bitter from that of the solutions of magnesium salts. The bitter taste of the $Ca(NO_3)_2$ solutions is probably due to the Ca ions. The mobility of the Ca ions is about the same as that of the Mg ions.

Solutions of ammonium sulfate give scarcely any salty taste; their taste is rather to be described as bitter. This taste is caused by the NH_4 ions and the undissociated molecules $(NH_4)_2SO_4$. The probability is that NH_4 ions have a bitter effect, since NH_4NO_3 solutions, besides creating a sharp, burning taste on the tip and edges of the tongue, also have a bitter taste.

To get substances whose solutions have a characteristic "metallic" taste, silver nitrate and mercuric chloride were selected. It was found that even in $\frac{n}{5000}$ solution silver nitrate could still be tasted, while in $\frac{n}{2000}$ its taste was very pronounced. From

the limit of taste of sodium nitrate solutions as given above approximately, it follows that at the dilutions just mentioned the taste of silver nitrate solutions is simply that of the silver ions. Silver ions have a peculiar puckering effect on the membranes of the mouth which, if the impression has not been too weak, will remain for some time. The taste is frequently spoken of as "metallic." At first it would seem that silver ions can be tasted in more dilute solutions than hydrogen ions; this is true when we compare chemically equivalent quantities, but since the atomic weight of silver is about 108, a $\frac{n}{5000}$ solution of silver nitrate contains 1 gram of silver ions in 46300cc, while an $\frac{n}{800}$ solution of hydrochloric acid contains 1 gram of hydrogen ions in 800000 cc.

Solutions of mercuric chloride can be very faintly tasted when $\frac{n}{2000}$, plainly when $\frac{n}{1000}$, the "metallic" taste being somewhat similar to that produced by silver ions. Mercuric chloride is not highly dissociated in solutions that are not very dilute. The concentrations just mentioned are such, however, that in them the salt is largely electrolytically dissociated. As Cl ions can not be tasted in $\frac{n}{1000}$ solutions, it is clear that we get here the taste of the mercury ions.[1]

The Relations of Overton's Work to the Taste of Solutions.

Ernst Overton in an interesting article, "Uber die osmotischen Eigenschaften der Zelle in ihrer Bedeutung für die Toxikologie und Pharmakologie mit besonderer Berücksichtigung der Ammoniake und Alkaloide" (Zeitschr. f. physik. Chem. 22, p. 189, 1897), gives a list of organic groups arranged according to the degree of retardation that they exert in preventing the substance in which they occur from passing through vegetable and animal membranes. The list beginning with the group that retards most is as follows:

1. The amido-acid group.
2. The carboxyl group.

[1] Compare the work of H. Dreser, Zur Pharmakologie des Quecksilbers, Ref. Zeitschr. f. physik. Chem. **13**, 37, 1894.

3. The acid-amido group.
4. The alcoholic hydroxyl group.
5. The aldehyde group.

When several of these groups occur in one and the same compound, the retarding action increases with the number of groups in a rapid geometrical progression; for example, while substances that contain but one alcoholic hydroxyl group readily pass through membranes, those that contain two or more such groups find increasing difficulty in doing so as the number of groups grows larger.

In order to affect the nerves of taste substances must be readily diffusible, as was previously pointed out; it follows, therefore, from the above table of Overton, that compounds containing the amido-acid or acid-amido group should have little or no taste. Glycocoll ($CH_2.NH_2.COOH$), which is soluble in about four parts of cold water, has a weak sweetish taste. In order to taste the substance, concentrated solutions or even a crystal directly must be taken into the mouth. Acetanilid, $C_6H_5 NH(C_2H_3O)$, though readily soluble has almost no taste even in saturated solutions. Asparagin, $C_2H_3.NH_2.CONH_2.COOH$, which dissolves easily in water, is almost perfectly tasteless even in its strongest solutions. Acetamid, $CH_3.CO.NH_2$, also readily soluble, does possess a characteristic taste, which, however, is not very strong. It is difficult to ascertain the true nature of this taste as it is not easy to eliminate the mouse odor that the solutions of this substance have. Overton emphasizes that the acid-amido group does not exert nearly as great a retarding influence as does the amido-acid group, hence the behavior of acetamid is perhaps such as would be expected. Urea, $CO.(NH_2)_2$, very soluble in water, has a slightly bitter taste reminding one of that of the magnesium ion. Biuret, $NH(CO.NH_2)_2$, readily soluble, is practically tasteless; its most concentrated solutions are very faintly bitter.

It is difficult to study the effect of the carboxyl group because acids dissociate yielding hydrogen ions the taste of which is so strong that it masks that of other molecules present in the

solution. The fact that solutions of sodium acetate, of sodium oxalate and sodium tartrate have no pronounced taste is evidence that the anions of these acids have but a slight effect, if any, on the end organs of taste.

The alcohols having but one hydroxyl-group, possess taste and also a very strong odor. As it is extremely difficult to exclude the smell of these substances while tasting them, nothing was done with them experimentally.

Great interest attaches to the polyatomic alcohols. Of these ethylene-glycol having two hydroxyl groups and glycerine with three hydroxyl groups have a sweet taste that can readily be detected in strong solutions. Erythrite with four hydroxyl groups and mannite with six are practically tasteless; only in very strong solutions were these substances found to be sweet. The taste of a sample of dulcite was pronounced to be nil even in the strongest solutions, while isodulcite and sorbite were found to be slightly sweet.

Turning now to the sugars, arabinose, lævulose, *d*-glucose and galactose were reported to be sweet, as were also maltose (malt sugar) and saccharose (cane sugar), while lactose (milk sugar) and xylose were found to have little or no taste. The The aldehyde groups occurring in sugars, seem to render them more capable of permeating membranes, and probably they also modify the compounds so that in their action on the nerve they increase the sweetish taste, which on the whole is characteristic of the alcohols containing several hydroxyl groups. The intensity of the tastes of the polyatomic alcohols and the sugars is then in general such as one would expect viewing the matter in the light of Overton's work.

The Taste of the Alkaloids.

Overton found that coniine, nicotine, sparteine, etc., very readily pass through protoplasm; of the alkaloids that contain oxygen, codeine, thebaine, cocaine, atropine, strychnine and brucine diffuse very rapidly, whereas morphine diffuses more slowly and ecgonine very slowly. The burning taste and the

characteristic odor of coniine and nicotine are well known, as is also the very bitter taste of sparteine. With the exception of thebaine, the other alkaloids mentioned also have pronounced bitter tastes. The taste of ecgonine, which, though very soluble, passes through membranes slowly, has been described as bitter-sweet. Thebaine seems to behave in an exceptional manner; it is very soluble, very poisonous, passes through membranes with great readiness, and yet is tasteless according to some authorities.[1] I have not been able to verify this since a sample of the substance was not available. With the apparent exception of thebaine, however, it is important to note that the alkaloids which diffuse readily through membranes and which are known to exercise a strong physiological effect on the nerves are also able to get at the nerve endings of the sense of taste, reacting upon the same with vigor, producing disagreeable burning or bitter tastes.

Colloidal Solutions.

As typical colloidal solutions may be mentioned solutions of dialyzed silicic acid, ferric hydroxide, aluminum hydroxide, also solutions of albumen, gelatine, gums, etc. These solutions are practically non-conductors of electricity, i. e., they contain few or no ions; they have boiling and freezing points that differ but very little from those of water. The rate of diffusion of colloids is very slow, and in general they are very inert in their chemical behavior. Besides those already mentioned, other characteristics of colloidal substances are that they have no definite solubility and that their solutions gelatinize when treated with certain reagents. These colloidal solutions are devoid of taste. This is very likely due to the fact that the molecular weight of colloidal substances is very large and their diffusion so very slow that they can not get at the nerve endings; though, because of their inert character, it is quite reasonable to suppose that, even if they were able to come into immediate contact

[1] See for example Watt's Dictionary of Chemistry 4, p. 681.

with the protoplasm of the nerve, they would probably not react with it sufficiently to produce sensations of taste.

Retrospect.

One may briefly summarize the salient points contained in the foregoing as follows:—

1. In order that a substance may affect the sense of taste, it must be soluble in water; it must be readily diffusible; and it must be capable of reacting chemically with the protoplasm of the terminals of the nerves of taste.

2. The modern theories of solutions lead to the conclusion that the taste of a solution that conducts electricity ought in general to be that of the ions and the undissociated molecules that the solution contains; furthermore, the taste of a solution in which ionization is practically complete should be simply that of the ions. This is supported by the results of the investigation of the taste of solutions of electrolytes above given.

3. Sour taste is caused by hydrogen ions. The sense of taste is able to detect hydrogen ions even in $\frac{n}{800}$ solutions. In more dilute solutions than $\frac{n}{200}$, hydrogen ions may cause simply an astringent sensation. The sour taste of acetic acid solutions has been found to be more intense than it ought to be according to the degree of dissociation of the substance. No explanation of this phenomenon has thus far been attempted.

4. Hydroxyl ions produce an alkaline taste, which can be perceived even in $\frac{n}{400}$ solutions. In strong solutions their taste is exceedingly disagreeable. Pure water, being very slightly dissociated, is tasteless probably because its undissociated molecules do not act on the protoplasm of the nerve.

5. Chlorine ions have a salty taste. The taste of common salt solutions is mainly that of chlorine ions. Chlorine ions can still be faintly tasted in $\frac{n}{50}$ solutions. Bromine ions also have a salty taste, which, however, is slightly different in quality from that of chlorine ions. The sense of taste appears to be able to detect chlorine ions at a slightly greater dilution than bromine ions. The ions ClO_3 and BrO_3 have a somewhat similar

taste; which, however, is not sharp and salty like that of chlorine and bromine ions. Iodine ions have a salty taste but it is different in quality and less intense than that of either chlorine or bromine ions. It takes about a $\frac{n}{6}$ solution of iodine ions to produce a distinctly salty taste.

6. The taste of NO_3 ions is slight, probably a trifle salty; only in strong solutions do they produce a sharp burning sensation on the tip and edges of the tongue. The ions SO_4 and CH_3 COO have but very little taste; the effect of the latter seems to be a trifle sweet.

7. The taste of sodium ions is slight. It is difficult to describe, being a smooth effect on the tongue somewhat similar perhaps to that produced by a very dilute solution of hydroxyl ions. Potassium ions have a more pronounced taste than sodium ions. It is a peculiar, bitter, rather disagreeable taste that can be much more readily detected than can that of sodium ions. Lithium ions have no pronounced taste, their effect is somewhat like that of sodium ions, though less in degree. Magnesium ions are bitter. It takes about a $\frac{n}{6}$ solution to cause a distinctly bitter taste. Calcium ions are bitter, but the taste is different in quality from that of magnesium ions. Ammonium ions also have a bitter taste. The taste of silver ions is "metallic"; they cause a peculiar puckering sensation on the membranes of the mouth cavity. Even a $\frac{n}{5000}$ solution of silver ions can still be tasted. Mercury ions can be faintly detected by the sense of taste in $\frac{n}{2000}$ solution. Their taste is "metallic" and their effect on the membranes of the mouth cavity reminds one of that of silver ions.

8. The intensity of the salty taste of the halogen ions decreases as the atomic weight increases. The investigation of the cathions also indicates that a relation exists between their taste and their atomic weights in the sense of the periodic law. When the taste of the ions is compared with their mobility as expressed by their speed of migration under the influence of the electric current, a number of instances are found that would point to the conclusion that the greater the mobility the more

intense is the taste; but there are many exceptions that show that the intensity of the taste produced by the ions is not simply determined by the readiness with which they can get at the nerve endings, but also by the reactions they undergo with the protoplasm, which of course are determined by the chemical character of the ion.

9. The intensity of the taste of solutions of substances containing amido-acid, acid-amido, alcoholic hydroxyl, and aldehyde groups was investigated, and it was found that the results obtained are in general such as one would expect viewing the matter simply in the light of Overton's determinations of the relative readiness with which these substances permeate plant and animal membranes.

10. It was pointed out that in general the alkaloids have a pronounced bitter taste, that according to Overton nearly all permeate protoplasm readily and that furthermore, they are known to exert a strong physiological action on the nerves.

11. Colloidal solutions are tasteless because the substances they contain diffuse very slowly and are chemically very inert.

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Bulletins issued since May 1st, 1898, are entered as second class mail matter and no charge it required by the University to cover cost of postage.

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BULLETIN OF THE UNIVERSITY OF WISCONSIN

NO. 36

SCIENCE SERIES, VOL. 2, NO. 2, PP. 33-198, PLS. 1-2

ASPECTS OF MENTAL ECONOMY

AN ESSAY IN SOME PHASES OF THE DYNAMICS OF MIND, WITH PARTICULAR OBSERVATIONS UPON STUDENT LIFE IN THE UNIVERSITY OF WISCONSIN

BY

M. V. O'SHEA,

Professor of the Science and Art of Education.

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PRICE 75 CENTS

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INTRODUCTORY.

In this essay I have ventured to discuss from a particular point of view the question, How can a student make the most of himself? In one or another of its aspects this matter is considered alike by religion, by psychology, by ethics, by education, by hygiene, and by other philosophies and sciences. Each regarding a special phase of man's being seeks to advise him concerning his conduct so that he may attain the highest possibilities of his nature. Thus, religion counsels him respecting the deportment which will prepare him for habitation in another world; ethics aims to so determine his demeanor that he may dwell in the spirit of justice with his fellowmen; education delineates the processes by which he may secure the fullest development of intellect and character. The phase of this large subject which is discussed herein is indeed a narrow but yet, I believe, an exceedingly consequential one. Taking a doctrine accepted by modern science, that, looked at in a certain light, a human being is seen to be a machine fashioned to do a given amount of work, depending upon the quantity of energy which may be utilized for this purpose, I have sought to examine the ways in which this energy can be most readily generated and wisely conserved so that it may be employed in profitable production of either a mental or physical sort.

The view-point I have taken is what might perhaps be called an energeic[1] one. If this should sound too materialistic to some readers they will certainly not be aggrieved when they

[1] I coin this word to express precisely a certain relationship of mind and body which is discussed at length in the course of the essay.

consider that there has been no attempt to examine the entire nature of an individual. No one could imagine that the only problem involved in a person's success in life relates to the generating and conserving of nervous force. This is surely important enough, but yet more important things follow. When one is in possession of his forces then the question arises, what shall he do with them? In what direction shall he expend them? What is really worth while? The answers to these queries must be sought for in the principles of religion, education, and allied departments of knowledge concerning human life.

I am well aware that I have discussed in an inconclusive manner some topics connected with my subject. Indeed, certain problems have been simply opened up for more detailed consideration later rather than settled in any satisfactory way. This is made necessary at the present time by the unbroken character of the field. So far as I know there has as yet been little serious effort to discuss deportment from an energeic point of view, and in a comprehensive, systematic form. All that has been done is of an isolated, fragmentary character, and most of the available data concern more or less simple processes which are likely to have their properties much modified when combined into the complex thing we call conduct. These data are scattered through a number of sciences; and what I have attempted to do is to gather up the most relevant of them and interpret them in the light of one another, and by the aid of observation and experience, keeping constantly in mind local practices and conditions. I regret that it has not been possible to investigate in a more thorough manner several of the matters treated; but if those who feel the lack of certainty will be stimulated to undertake detailed and exact studies for themselves, some good will have been done. I am convinced, though, (and this is a source of consolation), that for practical purposes it is often quite as efficient to direct an individual's attention to the consideration of a certain line of conduct as to presume to give him explicit directions respecting his actions.

It may occur to some that this subject is as a whole an extremely large and complicated one to be treated according to scientific methods. They may feel conduct consists of such a bewildering complexity of factors operating together that it is for the present impossible to handle it with that precision which is the *sine qua non* of scientific procedure. Science in our day is minutely analytic, dissective; it seeks to single out from habitual associates particular factors or phenomena and investigate their properties. It attaches relatively little value to investigation which cannot control the conditions accompanying a phenomenon to be studied; for when we take a thing in the large, when we cannot separate it from its *milieu,* so to speak, it is not easy to see what elements are really most active in determining its nature. But now so far as psychological experiment is concerned, it is utterly impossible by any known methods of investigation to cut off elementary psychical processes wholly from each other. Experimental psychology may attempt to investigate an isolated sensation, for instance; but such a thing is a pure abstraction. In the intricacy of the psychic organism one element never can be entrapped apart from others with which it has become inseparably associated through experiences no less in phylogenesis than in ontogenesis. The most that can be done is to limit the run, as it were, to hedge it in on every side; to have, that is to say, as few factors as may be entering into a problem. The results of the most accurate experiments then in the mental sciences are only relatively more exact than those of observation or experience. It may be permissible to point out in passing that in our time there is some danger of experimental psychology conveying the impression that it is more precise than it ever can be. In a considerable part of present-day scientific writings one is led to think that the most primary phenomena have been examined with mathematical accuracy, when as a matter of fact there must have been left out of account accompanying conditions which determined to a greater or less extent the behavior of the thing studied.

While in general the analytic method of experimental science is to be highly commended, still in some situations it is probable that more satisfactory results can be attained by studying a thing in the large than in its elements,—macroscopically rather than microscopically. The French school of psychologists, following the lead of Binet and Henri, maintain that more of genuine worth for science is gained by examining an individual human mind in its totality, so to speak, than in its elements; while the German school, represented notably by Kraeplin, take an opposite view,—that reliable results can be secured only by a study of the most elementary processes in different minds. The one studies the living, complex entity, the other dissects and examines relatively simple factors. The movement in our own country seems just now to be headed in the direction of the French rather than of the German school. At all events, it should be apparent that we can apprehend, and that truthfully, characteristics in an organism when various forces work together that we would miss if we concentrated our attention solely upon each separate factor. These latter are not differentiated enough, it may be, to claim our attention; it is only when a vast number of them co-operate, when their properties are pooled, so to speak, and we have a personality, that we discern the significance of their total influence.

So in the study of conduct there are certain advantages in viewing a person as a whole, as an entity whose distinctive attributes are not apparent in each primary factor of mind or body. And this may be done with something like scientific precision. To illustrate, I may describe with accuracy the conduct of a drunken man without investigating in detail the simple physical and mental processes which totalized beget the state of inebriation. If I see clearly and tell truthfully my story may be relied upon. So one may set forth the effects of certain modes of living upon the energies of the organism without studying the most elementary phenomena involved in the total process. A fact observed, whether it relate to exceedingly complex or markedly simple objects, is in any event a fact and as such is worthy

of our credence. Thus history may be considered to treat of the utmost conceivable complexity of subjects which, in their extremest analyzable form, are considered by neurology and analytic psychology. But the principles of history are not on this account to be regarded as less trustworthy than those of neurology. Microscopic study, just because of its minuteness, is not more reliable and trustworthy than macroscopic study; you can describe as well (and it may be better) the conduct of a horse as that of an amoeba. That it may be valid though, of course your description must be verifiable alike by experience and by experimental research *ad libitum;* but so long as it stands the test it must be accorded all the honors and privileges of scientific knowledge.

I know it is a hazardous thing to express an opinion upon matters respecting which every one is an authority. And if there is one matter more than another which needs no study to comprehend, it is that which has to do with the regulation of our daily lives. Here common-sense, elsewhere so little trusted, is esteemed a wise guide. It is one of the simplest principles of psychology that we all tend to make our thoughts and actions standards by which to estimate their own value. It is difficult for me to believe that the factors which have produced me are beyond improvement; what I do must be right. Every one entertains Phantoms of the Cave when such familiar things are under inspection; and this it is which makes it so hard to convince people that they should ever modify their conduct. But it ought to require no argument to prove that the self-standard in deportment is no standard at all. Because I have been living in a certain manner and have survived is no evidence that I could not have lived better by adopting a different régime.

A woman was recently discussing the subject of food, and contended that modern scientific investigation was valueless if not detrimental in promoting happiness in life. She had brought up a family in violation of all the rules of hygiene re-

specting diet, and she instanced her six grown sons and daughters to prove that hale and hearty children could be reared on "unhygienic victuals." As a matter of fact, however, these "stalwart" men and women are taking medicine half the time; and not one of them has yet accomplished anything of consequence in the world. But this woman, beholding them through a mother's eye, is convinced that perfection has been attained in their construction; while a disinterested neighbor sees the matter in a quite different light. It is a far cry from the grave to the most energetic and efficient living; and because one is alive is no evidence that he could not be more alive. It is not assured beyond question that one out of jail is a good citizen; nor is it at all conclusive that because one is "getting on" in the world he could not swing along with greater momentum by the aid of a knowledge of some of the principles of mental mechanics. It would indeed be a remarkable circumstance if by accident alone we should have hit upon the very best ways of ordering the minutæ of our daily lives, when it is seen how great advances, what discoveries of beneficial methods are made by careful study in other fields. If science can do so much for us in simple matters how much more ought it to help us in the most complex and intricate of all affairs,—the adjustment in harmonious relations of a human being to his environments. But the very complexity overwhelms the common mind, stops up the avenues of thought, and it falls back on the universal platitude of ignorance, "Oh! there's nothing in it anyway."

On the other hand, one too conscious of his demeanor in respect of the petty details of life is in so far limited in his efficiency. A mind turning in always upon itself or upon bodily processes throws the machinery of life out of gear. Speaking in general terms that mind is the best instrument that is concerned with objects outside of self, when the organism adjusts itself to the attainment of these ends; then things work together in harmony. This is the ideal. But yet through early ignorance or through the necessity of adaptation to waste-

ful conditions in our environments we may fall into practices that lessen the efficiency of our forces. By a little thought these prodigal habits may be supplanted by better ones, when the mind may again be free. Now, the requirements of mental hygiene do not demand one to be constantly dwelling upon his actions; they simply ask him to exchange certain not too deep seated habits by others, and to make these latter automatic as soon as possible. In the matter of producing energy, those who have charge of our dietaries and our living apartments are the ones who should become conscious of our needs; and if landlords and club managers were only experts in their business and could supply us according to our necessities, we should then be relieved from attending to such matters for ourselves, and greatly to our advantage. But as the situation exists in our midst it seems needful that those who suffer should search out their own remedy; and it is to be hoped that this will not breed too great consciousness respecting in a way trivial matters, but only that it may serve to bring about certain simple modifications in diet and living which will soon fall into the regions of habitual and subconscious action.

CHAPTER I.

THE RELATION OF MIND AND BODY.—AN ENERGEIC CONCEPTION.

§1. *An Historical View.*—From the earliest times men have debated over the connection between the physical and the mental in the human organism. This has been the problem of chiefest concern, at various stages in the development of thought, alike for mythology, for religion, for philosophy, and in our own era for experimental science. The conception of mind most characteristic of primitive reflection in the individual as in the race regards it as a tenant of the body ruling over and directing its activities, and being influenced itself in some measure, great or small, by bodily conditions, and what may be called physical or outward demeanor. This notion does not postulate any organic relationship between, much less identity of, mind and body. There is but a sort of tangential relation, so to speak; and the spirit can if it will free itself wholly from the control of the material structure in which it is momentarily entombed. It is only when the volitional element in one's being is lethargic that he yields to the promptings or suggestions of his physical self, which, most unhappily, are natively of an evil mien. Holding this view men believed during long epochs in human history that they ought to scourge and maltreat the body that they might thus purify and strengthen the spirit; for if the animal be not held under subjection by such discipline it will endanger the supremacy of the man: a doctrine quite contrasted to the theories of these latter days, when it is proclaimed on every hand that the more respect we pay the body, and the kindlier and more faithfully we attend its needs the greater will be the reward in spiritual exaltation and freedom.

Correspondent with the development of physical science in its earlier years, however, there gradually arose another and a vitally different theory,—that in an ultimate analysis mind

can be reduced to material terms. This conception becomes easily established in the evolution alike of the racial and of the individual mind, since the phenomena occurring in mental disease, and particularly in injury to or degeneracy of the central nervous mechanism lend themselves readily to such interpretation. People remark that if the brain suffer damage from any cause some mental defect or deficiency usually ensues; and when for whatever reason the cerebrum becomes inactive, there is no evidence of any supra-cerebral activity remaining. So far, in short, as we can observe mental activities *ab extra,* they appear to be directly dependent upon or rather aspects of neural processes. This second view then makes mind a phase or phenomenon of matter,—one of a group of physical forces originating in the degradation of highly organized chemical substances.

There is yet a third hypothesis[1] which regards the mind and the body, so far as it passes opinion upon the essential nature of each, as distinct entities, but in some inexplicable manner bound to each other in such a way that the activities of the one necessitate correlated activities in the other. The advocates of this theory pin their faith to what may be styled a dynamic, or better, energeic relation between mind and body. They do not deem it needful to explain how this relation is possible, although theories looking in this direction are not wanting. A common one espoused by James and others considers the nerve cell as the instrument, and the sole instrument, by which mind may be displayed in a material world; and if the neural elements which constitute the *via media* for this physical exhibition of a non-physical order of being be deficient in any way, then simply mind cannot manifest itself at all, or only in a manner we call defective or abnormal.

[1]Typical presentations of this the now prevalent view may be found, among many other references, in Lotze, *Microcosmus;* Darwin, *Descent of Man;* Romanes, *Mental Evolution in Man;* Wallace, *Darwinism;* Fiske, *Destiny of Man in the Light of His Origin;* Drummond, *Ascent of Man;* Wundt, *Human and Animal Psychology,* pp. 5–7 and 440–445; James, *The Will to Believe,* chap. on Reflex Action and Theism.

§ 2. *The View of Experimental Science.*—Whatever be the true philosophy of the inter-relations of mind and body, modern experimental science is quite assured in the view that they are inseparably connected in their activities. The doctrine that "every psychosis is accompanied by a neurosis" has been adequately demonstrated for many people by the results of experimentation in physiological and psychological laboratories,[1] as well as in the laboratory of Nature, pure and simple, wherein she reveals to us through pathological disturbances the normal order of things; although, of course, complete and final evidence upon this subject is for the present at least quite beyond the skill of science to obtain. But it seems reasonably certain for one thing (the only one that concerns us here), that all mental activity, and physical as well, involves

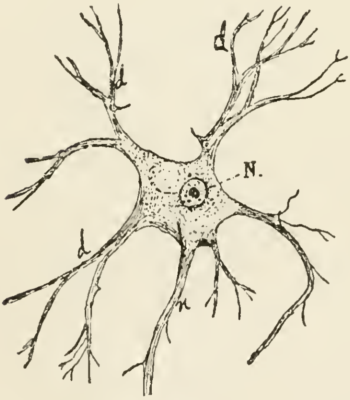

FIG. 1.

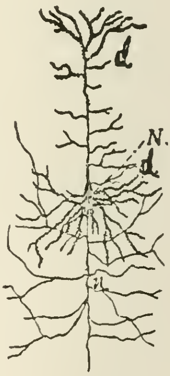

FIG. 2.

Figs. 1 and 2.—Representations of typical nerve cells (Donaldson, Growth of the Brain, pp. 143 and 145) designed especially to show the elements concerned in the reception of stimuli, d; in the generation and storage of potential nervous force, N; and finally in the transmission of kinetic nerve energy, n.

the expenditure of energy generated in the nuclei of neural cells. The architecture of the cell, in the absence of more suggestive experimental data, would of itself lead one to this

[1]For the opinions of investigators as Mosso, Lombard, Maggiora, Kraepln and others, see the Pedagogical Seminary, Vol. II, No. 1, pp. 13–17; Scripture, *The New Psychology*, chap. XVI; and Educational Review, Vol. XV, p. 246 et seq.

inference. The plan of construction, as doubtless every one knows, is simple,—a central body or nucleus serving the purpose of husbanding resources, as it were; and, radiating out from this are fibers or pathways some of which are designed to convey impressions in the form of sense stimuli to the nucleus of the cell, while others bind into a social union cells in different regions of the cerebral community. (See Figs. 1 and 2.)

The bodies comprising the nucleus of the cell are believed to be of a highly complex and unstable chemical composition,[1] in consequence of which they are easily broken down, the energy represented in their union thus being liberated and dissipated ultimately in incitement to motor activity, or possibly in thought. Neurology assumes, what was stated above, that all mental and physical action requires for its initiation and maintenance the liberation of a measure of this mysterious force held *in potentia* in the nuclei of nerve cells.

People do not commonly think, in part because they do not reflect upon the matter, that mental activity occurs at the expense of the contents of cerebral cells. Even critical introspection reveals thought as a spiritual activity dissociated from or at least not dependent dynamically upon physical processes. It is not easy for me to conceive that my ideas are linked to material agencies, and remain dormant except when these are active; no matter for present needs which is cause and which effect. And yet if one will note the physical accompaniments of his thinking he will not lack for opportunities to see that arduous mental work requires a comparatively great supply of blood headwards, which is shown in distention of blood vessels and in a sense of pressure or strain in the cephalic regions. Every student must have observed also, if he at times becomes attentive to the bodily concomitants of his mental processes (which, let it be said in passing, is a tendency not generally to be nurtured, but rather to be combated) that continued study increases the temperature of the head.

[1] Ladd, *Physiological Psychology*, pp. 13 and 14, gives the following formulæ for some of the substances: protagon, $C_{116}\ H_{241}\ O^{22}$ P.; cholesterin, $C^{26}\ H_{44}\ O + H_2\ O$.

These phenomena are easily observable in psychological experiments, wherein it is possible to show that when a subject exerts his mind in the effort to solve a difficult problem, for example, the volume of blood in the cerebral locality increases. It was the physiologist, Angelo Mosso,[1] I believe, who first directed the attention of scientists to this in his investigations with the plethysmograph. And he was able to demonstrate the same phenomenon also in another experiment. A subject is placed upon a delicately constructed balance which remains horizontal while he is in a condition of mental repose; but when he is summoned to severe intellectual effort, or when any lively emotion is aroused, the balance tips in the direction of the head, showing that the blood is surging brainward and so of course away from the limbs. The increase in temperature during mental activity has been studied by Lombard, Schiff, and others by means of the thermo-electric needle plunged into the brains of dogs and other animals.[2] When in this latter case any sense was stimulated, as smell, the needle if placed in the olfactory region of the brain would show that heat was being liberated.

The significance of these well-known but yet little appreciated phenomena becomes apparent when they are interpreted in view of the accepted explanations of similar phenomena occurring during muscular exertion. It is a simple physiological fact that the blood supply in a muscle is greater during activity than while at rest, caused by the necessity of removing and repairing the increased waste produced by the degradation of

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[1] Reference is made to this phenomenon in Mosso's *Fear*, p. 68. The subject is treated in detail with respect to methods of investigation, and results in *Die Ermüding*, pp. 195 et seq. There is a very good résumé of recent investigation relating to the effect upon circulation of intellectual and emotional activity, together with the presentation of results of original researches, in the Psychological Review for January, 1899, by Angell and Thompson,—*The Relation between Certain Organic Processes and Consciousness.*

A. Binet and V. Henri in *La Fatigue Intellectuelle*, pp. 81 et seq., recognize that intellectual activity produces dilation of the cerebrum, but they do not attach so great importance to this phenomenon as many do. Their discussion does not bear directly upon the problem involved here, however.

[2] See Pedagogical Seminary, *loc. cit.*

living tissue while engaged in work. Now, it may be readily inferred that the phenomenon of augmented cerebral circulation during vigorous intellectual or emotional activity is identical in principle with the muscular phenomenon just noted. Corroborative testimony in proof of this energeic dependence of mind upon cerebral cells is afforded by the observations of physicians[1] who maintain that certain toxic products of nervous action increase *parri passu* with intensified intellectual or emotional activity. Mosso's demonstration of a distinction between muscular and neural fatigue[2] requires for explanation the assumption that nervous as well as physical action results in the accumulation of a sort of debris in the system, which is undoubtedly nothing but worn-out or degraded nerve substance, and which may heap up to such an extent as to disturb the normal functions of the neural mechanism. Especially does it tend to throw out of gear the inhibitory apparatus, paralyzing the fatigue sense, as some one has said, and thus removing the natural checks to excessive physical or mental exertion, when the organism continues in activity beyond the safety limit.

The experiments of Hodge[3] apparently show quite conclusively, in the case of animals at any rate, that the activity of the cell depletes the nucleus of its contents, revealed in a gradual shrinking while stimulation continues, as shown in Figs. 3 and 4. This phenomenon, which he was able to detect while experimenting with a living cell under stimulation, was observed also in the examination of animals at night after a day's activities, and in the morning when they had passed a long period in rest. In the first instance the nuclei of the cells were shrunken, while in the morning they presented a repleted appearance,

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[1] For instance, by Cowles: *Neurasthenia and Its Mental Symptoms;* Beard: *Neurasthenia*, edited by Rockwell; Mills: *Mental Overwork and Premature Disease Among Public Men*, Smithsonian Institute, No. IX of Toner Lectures.

[2] See for further discussion, p. 52.

[3] Some Effects of Electrically Stimulating Ganglion Cells, American Journal of Psychology, vol. II, p. 376 et seq.; and, Process of Recovery from Fatigue Occasioned by the Electrical Stimulation of Cells of the Spinal Ganglia, Am. Jour. of Psy., vol. III, p. 530 et seq.

showing that the demands of waking life had resulted in partial exhaustion of their stock of force-producing materials.

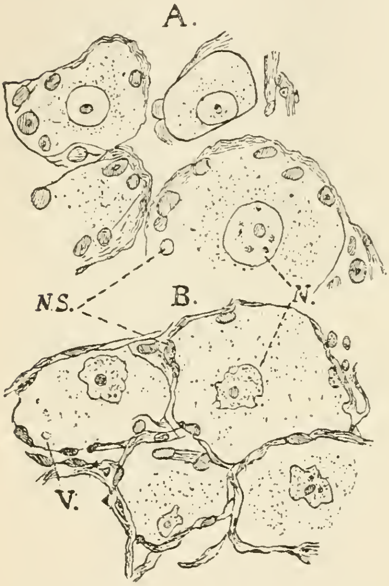

FIG. 3.

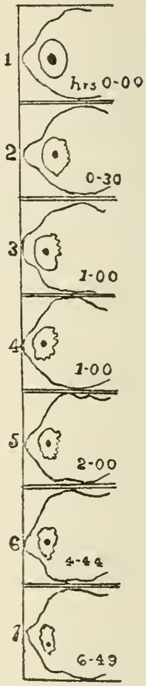

FIG. 4.

FIG. 3.—Two sections, A and B, from the first thoracic spinal ganglion of a cat. B is from the ganglion which had been electrically stimulated through its nerve for five hours, A from the corresponding resting ganglion. The shrinkage of the structures connected with the stimulated cells is the most marked general change. N, nucleus; N. S., nucleus of the capsule; V., vacuole x 500 diameters. (Hodge.)

FIG. 4.—Showing the change observed in the nucleus of the living sympathetic nerve cell of the frog, as the result of electrical stimulation. At the beginning of the experiment the nucleus is seen to be replete with what we may call potential nerve energy; but after thirty minutes of stimulation it appears somewhat shrunken, and the shrinking increases as the experiment proceeds. At the end of six hours and forty-nine minutes the shrinking of the nucleus is very marked. (Donaldson,[1] after Hodge.)

§3. *Neural Fatigue: Its Nature and Motor Effects.*—Modern science then conceives of the brain as a generator and reservoir, so to speak, of energy which is essential to the activity of body or mind. A proposition growing out of this is self-evident,—that when one's resources are expended in one direc-

[1] Growth of the Brain, p. 320.

tion they cannot at the same time be employed in another. In amplification of this axiom attention may be called to what every one has doubtless observed, that when one is engaged in hard muscular labor, he is less keen and vigorous in his mental processes; and when he is under great emotional excitement he cannot accomplish so much intellectually. Again, when the vitality of the system is dissipated in repairing the ravages of disease, the individual is unable to command so great force in the accomplishment of either physical or mental tasks. This conception, which is endorsed by experience and substantiated by physiological and psychological science, is a most important one as it relates to the ordering of the daily life of any person and especially that of a student. To but indicate its bearings here, it may be pointed out that the vigor, efficiency, and spontaneity of either physical or mental activities in the business, social, and educational world depend in some degree upon the amount of nervous capital one has on deposit in the central nervous mechanism. Abundant research has proven, it seems, that cerebral depletion (and depletion is, of course, a relative term in respect of the readiness with which it ensues in different people) reduces the force of muscular effort, renders attention less concentrated, resulting in a gradual obscuration of mental vision, and estranges the emotional nature, begetting a general condition of disphoria and apprehensiveness, and removing restraints upon anti-social impulses, as jealousy, anger, irritability, and similar traits of a low order of development.

Mosso,[1] Maggiora,[2] Lombard,[3] Bryan,[4] Kraeplin,[5] and others have shown that in a condition of fatigue muscular activity is lessened in force and reduced in rapidity; and this

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[1] Ueber die Gesetze der Ermüdung, Archiv. für Phys. (DuBois Reymond.) Hefts, I and II, 1890.

[2] Ueber die Gesetze der Ermüdung. Untersuchungen an Muskeln des Menschen. Archiv. für Anat. und Phys. (DuBois Reymond.) Physiologie, 1890, pp. 89–243.

[3] Some of the Influences which Affect the Power of Voluntary Muscular Contractions. Journal of Physiolgy, vol. XIII, pp. 1 and 58.

[4] The Development of Voluntary Motor Ability, Am. Jour. of Psych., 5, p. 123 et seq.

[5] A Measure of Mental Capacity. Popular Science Monthly, vol. 49, p. 756.

is no doubt to be accounted for in largest part by the fact that what we are wont to call muscular fatigue is in reality quite largely central or nervous fatigue. When a subject under experiment continues to exert force through the arm, say, until his muscles become perfectly inert, they may then be stimulated with electricity to act with initial vigor, indicating that they are still in workable condition; and after a period of stimulation in this way, the will of the subject remaining quiescent, he can again voluntarily energize the arm, as is shown in the following figures.

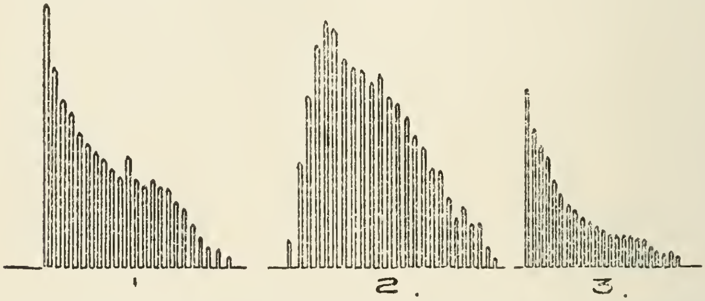

FIG. 5.—Showing ergographic tracings (1) in voluntary effort, (2) in electrical stimulation of nerve, (3) in electrical stimulation of muscle. (Scripture[1] after Mosso.) The relative heights of the tracings represent the relative amounts of energy expended in the several forms of stimulation. It can be seen that in voluntary effort the subject gradually loses power of exertion and is soon unable to exert any force whatever; but if at this point a nerve leading to the muscle which has been acting (in this instance the middle finger was exercised) be excited by electricity, the tracings show that the muscle is as vigorous as ever. The fatigue in the voluntary effort must then have been central or mental. Again, if when action ceases from nerve excitation the muscle be directly stimulated there is once more a return of power, indicating that the muscle itself fatigues much more slowly than the nerve mechanisms concerned in voluntary effort.

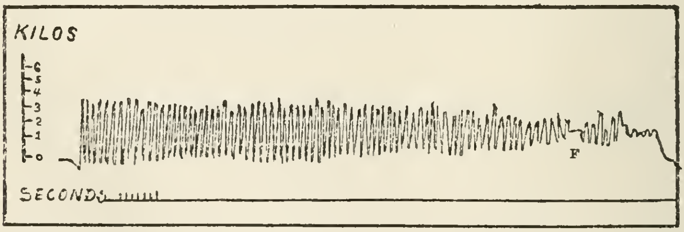

FIG. 6 shows the rhythm in the fatigue of voluntary effort (Scripture[2]). At F is shown a period when the subject could exert no force whatever, although he earnestly endeavored to. Soon after this space of paralysis, however, there is a return of ability again for a brief time. These tracings were obtained upon the dynamometer by means of the hand grip.

[1] The New Psychology, p. 231.
[2] Ibid., p. 229.

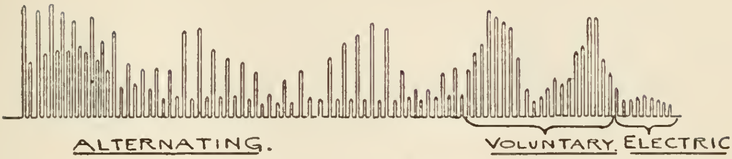

FIG 7. This figure (Scripture[1] after Lombard) shows the independence of muscular and voluntary fatigue. Lombard first stimulated a muscle by volition, then by electricity, and continued the stimulations alternately as indicated in the figure. At first the voluntary tracings show greater force exerted, but this is gradually lost until the effect for volition and from electrical stimulation are about equal. Then there is a recovery of volitional power, which subsides again, only to return in a sort of rhythmical period, which is very apparent from the tracings.

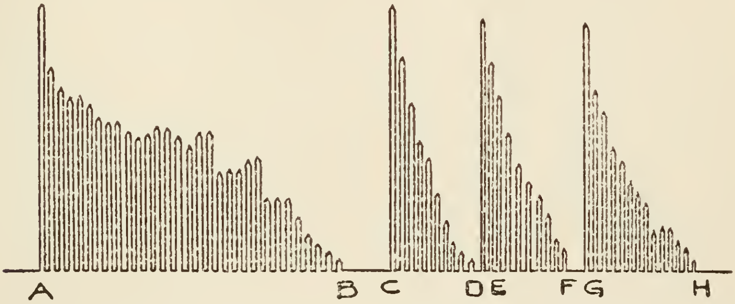

FIG. 8 shows the effect of mental work upon the power of contraction of the finger at various hours of the day. (Mosso, loc. cit.) The first curve, from A to B, indicates the amount of work which could be done at 9 a. m. From 2 p. m. until 5 :30 p. m. the subject was under great mental strain while conducting an examination in the university. After the examination, at 5 :45 p. m., the curve from C to D was gained. The first contraction of the finger shows as much power as in the morning, but the energy is soon exhausted. Then after supper, at about 7 :30 p. m., the increase from E to F was taken, and it indicates a slight increase in the endurance of energy. Finally at 9 p. m. the fourth curve was made, showing a slow recovery of original power.

This principle in its general bearings has been recognized practically in every-day experience, particularly in the training of athletes; for it is well known that their physical vigor and endurance depend in great degree upon their mental condition (See Fig. 8), or as the saying goes, upon their nerve. They are expected during the season of training to secure an abundance of food and sleep, and to abstain from dissipation so as to keep the nervous system in thorough repair; and it would doubtless not be an overstatement to say that athletic contests are won by virtue of the power and control conferred

[1] Ibid., p. 232. The figure is a copy made by Scripture from an original record furnished him by Lombard.

upon the athlete whose life is ordered in conformity to the requirements of neural hygiene rather than by superiority in muscular brawn *per se.*

The visible manifestation of cerebral fatigue most in evidence in the affairs of daily life is the lack of power to secure delicate and sustained co-ordination of bodily activities. Tasks demanding exact control and fine adjustment of muscles, as in delicate workmanship for instance, are exceedingly difficult when one is nervously exhausted. The explanation is doubtless found in the fact that different sections in the brain are charged with the control of certain definite motor processes, one section having general oversight of the large, coarse, fundamental movements, a second one governing the secondary and more complex movements, while still other sections control the peripheral, the most finely adjusted movements,—those for instance, involved in the co-ordinations of the fingers and the articulatory apparatus in speech.[1] This highest level, to employ Hughlings-Jackson's term,[2] may be regarded as the co-ordinating mechanism, *par excellence,* of the nervous system. Now, in cerebral fatigue, as in intoxication or mental disease, this level seems to suffer first because it is the most unstable; and nervous depletion will then manifest itself at the outset in inability to delicately correlate these most intricate movements.

This is at the root of much of what in the common affairs of life we call "carelessness," one of those terms which conveniently covers up a lack of critical analysis, grouping, and interpretation of phenomena. An individual who in a condition of fatigue is performing a task requiring exact adjustments of any kind, as fine writing for instance, will be unable to co-ordinate his actions so perfectly as when nervously refreshed, and this will result in blundering, coarse work. Warner[3]

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[1] For a fine treatment of this subject see the Pedagogical Seminary, Vol. VI, No. 1, pp. 5–65. The matter is brought down to date in this article. See also Mercier, *Sanity and Insanity,* Chaps. I and II.

[2] See Anderson, in Hack Tuke's *Dictionary of Psychological Medicine,* Vol. I, pp. 440 et seq. for a discussion of Hughlings-Jackson's theory, which seems now to be accepted by practically all physicians.

[3] *The Study of Children,* pp. 52 et seq.

ascribes this want of precision, which is simply inco-ordination carried to a point where it becomes noticeable, to the spasmodic functioning of nerve cells in a condition of fatigue. The inhibitory apparatus does its work less efficiently; but inhibition is absolutely essential for fine adaptations in motor activity. The Hughlings-Jackson theory would account for the phenomenon under consideration by declaring that the co-ordinating areas in the brain are unable to act with accustomed authority, and movements result which are not so fully under the direction of the will.[1] This view is strongly supported by data gained from the investigations of Mosso,[2] Lombard,[3] and others. But whatever the neurological explanation may be, it is enough for practical purposes to recognize that the exhaustion of nerve centers results in a general lessened power of delicate co-ordination of motor activities.

Again, as was intimated above, fatigue has a retarding influence upon the rapidity of physical action.[4] This phenomenon is apparent in the case of athletes who are contesting in activities demanding ready response to stimulus. When fatigued they do not start so readily in running, or gather themselves so quickly or act with such continued force in defense or offense where promptness in execution and sustained power are the decisive factors. When it is realized how much of the success of life depends upon quickness and certainty of action in the countless situations requiring these qualities in which one is placed every day no matter what his calling may be, the importance of preserving to the fullest extent possible the hygiene, or perhaps better the vigor of the brain can be appreciated.

§4. *Neural Fatigue: Intellectual Effects.*—While nerve depletion has indeed a very unhappy influence upon motor abilities, still the harm done here is probably not so great as that

[1] Cf. Scripture, *The New Psychology*, pp. 228 et seq.
[2] Loc. cit.
[3] Loc. cit.
[4] See Scripture, op. cit., pp. 128–129, and 243 et seq.; also Bryan, on *The Development of Voluntary Motor Ability*, Am. Jour. of Psy., 1892, p. 123.

sustained by the intellectual faculties. The latter consequence of brain fatigue is of chiefest concern to the student alike in his immediate daily duties and in his future vocation, which will for the most part require of him keen perception, accurate, ready memory, and, above all, careful and judicious reasoning. From what has gone before it must be apparent now that fatigue impairs those cerebral conditions which are essential to normal intellectual activity; and the most prominent effect of this in the mental life is to render attention less concentrated and enduring than when one is in good neural form, so to speak. Any person who has endeavored to apply himself to arduous undertakings when his resources have been too heavily taxed knows that it is with great difficulty he can hold his mind to the thing in hand, and he is likely not to succeed at all in the attempt. As James has said,[1] one grasps at everything in order to find relief from the object before him. At this time ideas crowd into the focus of consciousness which in seasons of mental vigor can be inhibited; and the upshot of it is that distraction ensues; the mind grows inaccurate and lethargic, and arrives finally at a state which, lacking a better term, we may name stupidity.

From the point of view of neurology the dispersion of attention in cerebral fatigue is simply explained. It has already been said that the co-ordinating, the regulative functions of the brain are disturbed in neural depletion, and there attends this condition a sort of independence of the various nerve centers resulting in lessened subordination of irrelevant motor activities. The individual does things that in better times he would be able to inhibit. Now, the neural capacities essential for right physical co-ordination are, it seems, requisite as well for mental co-ordination; and what renders one impossible will interfere also with the proper action of the other Concentrated attention requires the convergence of the mental powers upon one point, with of course restraint of disturbing impulses; but as the inhibitory processes are less vigorous and constant in fatigue,

[1] *Psychology, Briefer Course,* p. 225.

mental application is as a consequence less perfect. Ill-adjustment, disperseness, whether found in physical or mental action, are due to the same causative agencies. Mental degeneracy begets physical as well as psychical inco-ordination; imbecility is characterized no less by lack of control and balance physically than mentally. It seems as if we are able to say that on the whole those who have the surest motor control have at the same time superior possession of their mental powers.[1]

When it is remembered that fatigue dethrones attention, so to speak, it is not difficult to see why it should so soon beget stupidity, since a scattered mind cannot exhibit keenness, readiness, or accuracy in any of its operations. We would expect in the first place, that perception would be less discriminating, and this has been demonstrated by extensive investigations upon the several senses.[2] The writer has studied this subject in the schools of Buffalo, N. Y., making use of simple experiments which in a way tested the keenness and accuracy of interpretation of sense stimuli; and he has found that two and one-half hours' work in school lessens ability on the part of most pupils to discriminate colors, as tested by sorting colored yarns, or sounds as determined by the tone tester, or touch sensations as determined by the aesthesiometer, which Griesbach claims is the best test for mental fatigue.[3] The data yielded by these studies are in general in accord with those reached by such investigators

[1] For a summary of recent investigation relating to this subject, see Burk, *From Fundamental to Accessory in the development of the Nervous System*, Pedagogical Seminary. vol. VI, No. 1, and Reprint. See also Oppenheim, *The Development of the Child*, chaps. III, IV, V; Warner, *The Study of Children*, chaps. III to XIII; Donaldson, *The Growth of the Brain*, especially chap. XVIII; Halleck, *Education of the Central Nervous System*, chap. XI; Mercier, *The Nervous System and the Mind;* Ross, *Diseases of the Nervous System;* Flechsig, *Seele und Gehirn*, 1896; Hartwell *Add. and Proc. N. E. A.*, 1893; Ireland, *Blot on the Brain*, p. 257, et seq.

[2] See for the results of some investigations: Gilbert, *Studies upon School Children in New Haven*, in Studies from the Yale Psychological Laboratory, vol. II; Sinclair, *School-room Fatigue*, Educational Foundations, May and June, 1896; Dresslar, *Fatigue*, Journal of the Anthropological Institute, 1888, p. 153 et seq.; O'Shea, *When Character Is Formed*, Pop. Sci. Mo., Sept., 1897; also, *Some Practical Phases of Mental Fatigue*, Pop. Sci. Mo., August, 1899.

[3] Too much reliance, however, should not be placed upon the results of the æsthesiometric test. For myself I never could feel quite sure of my data. See for a critical discussion of this method two articles by Leuba and Germann in Psych. Rev., Nov., 1899.

as Kraeplin,[1] Burgerstein,[2] Sinclair,[3] and others.[4] These results will certainly not awaken surprise in any one who has observed the sharpness of his own senses at different hours during the day, and under varying circumstances with respect to fatigue. One may hear those about him say frequently something like the following: "I derive much greater benefit from visiting an art gallery in the morning than at 4 o'clock in the afternoon;" or "I find more pleasure in going out into the fields and coming in contact with nature in the morning hours than later in the day, for I see more, or at least I appreciate more; everything has a meaning for me now which is not apparent at other times. There are details and harmonies in sound, in color, and in form which I apprehend when I am refreshed but which I miss when my mind is tired." And the *rationale* of this is not obscure. It is not that there is less of beauty and richness in nature in the late hours of the day, nor that the visual or auditory sense organs are incapable of receiving stimulations therefrom; but the structures in the brain through which interpretation proceeds, because of the wastedness of their substance, if one may so speak, and the accumulation of obstructive materials, hinder the efficiency of the mind's action. Doubtless every student has noticed that when his energies are at a low ebb, whether abnormal in persisting throughout the entire day, or week, or month, or whether occurring only at intervals in the daily rhythm, yet in any case his perceptions become less keen and accurate, and he grows dull in all work that depends upon clearness of perception, as in the apprehension of forms in language, to some extent in mathematics, and to a considerable degree in the mechanic arts, not to mention other studies.

The senses are not the only nor the principal losers when the mind is over-wearied. Memory, both in its retentive and recol-

[1] A Measure of Mental Capacity, Pop. Sci. Mo., vol. XLIX, p. 756.
[2] Quoted by Kraeplin, loc. cit.
[3] Loc. cit.
[4] Since the above was written. the writer has read *La Fatigue Intellectuelle*, by A. Binet and V. Henri, in which the propositions herein set forth are in the main substantiated. See for a recent summary of studies upon this point, Kotelmann, *School Hygiene*, chaps. VII and VIII.

lective functions, becomes halting and unreliable. Who has not observed this in his own daily experiences? Ideas which one has firmly fixed in his head, and usually has in hand when he needs them, cannot now be readily summoned before consciousness, and often keep out of reach altogether. One has greater difficulty, too, in making ideas fast now than on other occasions. It seems as if the bewildering mechanism of the associative system, regarded from the neural point of view, becomes in a measure thrown out of gear, one might say, in fatigue; and in this event, memory processes easy and natural in normal mentation are so no longer. Under such circumstances one is apt to find that making use of devices for recalling ideas that at other times prove useful now are worthless. There is apparently an obliteration of old mental pathways; the energies of intellection are not discharged in the customary grooves, and the thought life then becomes to a greater or less degree either monoideistic or atomistic. As Ribot says,[1] "Fatigue in every shape is fatal to memory. The impressions received at such time are not fixed, and the reproduction of them is very laborious and often impossible. . . . When the normal conditions are restored memory comes back again."

It is not needful to linger over the significance of these facts for the student. His success in the acquisition of learning; or to put it in a way which would better represent the chief aim of education, in building up a unified personality with interests and activities adapting him most harmoniously to his social and natural environments,—his success in this depends so greatly upon the power of retaining impressions and summoning them forth when needed to guide action, that it would be impossible to overestimate the mischief that circumstances can do which militate against achievement of this sort. And then, regarding the immediate demands made upon the university student in his class-room, it is evident that the incapacity to fix firmly and in such a way as to be able to recall readily the ideas gained in the different studies is a thing of serious mien, as those who draw too heavily upon their energies in dissipation, in neglect

[1] *Diseases of Memory*, chap. V.

of the requirements of food, air, and exercise, or in other ways, doubtless have occasion frequently to realize.

Fatigue works most serious harm in the elaborative or reflective processes. Reason requires co-ordination of ideas; it necessitates holding before consciousness in a single act of thought two or more objects, viewing them together to discover the relations which they bear toward one another. It can be seen that to accomplish this requires good control and balance neurologically, and so psychically. But this is just what fatigue makes impossible, not absolutely of course, but relatively. Any person's experiences will afford illustrations in plenty. We all know how difficult it is, or even how impossible it is to attend to matters requiring elaborate reasoning at a time when the vitalities are run low. We generally defer the consideration of such matters until a more favorable period when mental strength has been regained. We attack our mathematical problems in the morning rather than at 5 o'clock in the afternoon. Even social custom has recognized this and has assigned the later hours of the day to occupations and pastimes requiring little concentrated effort of mind.

§ 5. *Neural Fatigue: Emotional Effects.*—It will not be needful here to do more than to refer briefly to the fact that the cerebral states which give rise to physical and intellectual inco-ordination and errancy have a similar effect in principle upon the emotional life. People are generally aware of this, and they freely condone the bad temper of individuals at certain seasons because of their unhappy physical condition. If one studies the matter at close range, he can see that the people who surround him are sometimes transformed in temperament under an ordeal which overdraws their account in the nervous system. It will of a certainty impress one who will turn his attention to the matter to observe how in a siege of neurasthenia anti-social qualities, as irritability, jealousy, hatred, anger, and the like take possession of an individual who in fairer weather is well poised and not too conscious of self in relation to others in his neighborhood.

If one should seek for an explanation of these phenomena, he would find the most rational one, and one in every way consistent with the principles involved in the preceding discussion, in the theory of recapitulation; which postulates that the individual retraces in some measure and retains in his own being to a certain extent the principal mental structures, intellectual and emotional, developed throughout racial history. The emotions most prominent in earlier phylogenetic epochs have been those concerned with the preservation of self against the enemies lurking everywhere, and which constantly threatened annihilation.[1] It was self against all the world else. The development of the altruistic or social emotions has been of very recent origin in racial evolution; and by virtue of a principle of heredity whereby latest developed phylogenetic characteristics are most unstable in ontogenesis, one is warranted in holding that while the social emotions are for the most part pre-eminent in the individual under normal conditions, yet these very emotions are most affected in fatigue, when the last formed and highest areas of the brain are first disturbed in their functioning. The process in racial ascent of gradual specialization of brain areas to take on more and more delicate and elaborate motor and psychic functions has resulted seemingly in the highest bodily, intellectual, and emotional activities becoming so intricately interwoven that one cannot suffer except at the expense of the others. Speaking neurologically then, the conditions requisite for co-ordination in intellectual and motor activities are requisite for the efficient control by the highest social emotions of those which are of a lower order, and represent earlier predominant characteristics alike in phylogenetic and in ontogenetic history.[2] A matter

[1] One is impressed with this thought as he reads accounts of animal life in its native wildness,—such accounts as one finds in Kipling's books, or in Thompson's *Wild Animals I Have Known*, or Cornish's *Animals at Work and Play*.

[2] For a detailed presentation of this theory, see, Marshall: *Biological Lectures and Addresses*, lecture on Recapitulation; Morgan: *Habit and Instinct*, whole book; Drummond: *Ascent of Man*, whole book; Le Conte, *Religion and Evolution*, p. 133 et seq.; Oppenheim, op. cit., chaps. I and II; Haddon: *The Study of Man*, Part II; Baldwin: *Mental Development, Methods and Processes*, chaps. I, IV, XIII; Hall: *Fear*, American Journal of Psychology, vol. VIII; Burk, op. cit.; Pedagogical Seminary, vols. III, IV, V, articles on Reverie, Mental Automatisms; Bullying and Teasing, Games and Plays, Truancy, etc., etc.

which is well recognized may be alluded to in this connection,—while under the influence of alcohol,[1] or in cerebral disease,[2] lower and more egoistic impulses usually gain mastery of the individual; and thus in some of their effects fatigue, cerebral disease, and intoxication seem closely related, explicable upon the supposition that all three attack the highest levels in the brain first and prevent, therefore, full and sure control of lower areas.

Again, it has been emphasized by students of this particular phase of fatigue, as Cowles,[3] Beard,[4] Dresslar,[5] and Mosso,[6] that fears which in the normal life are held in check are now apt to assert themselves and color the emotional life. There rises up in the early stages of fatigue a sense of dread of an indefinite something which is about to happen; and, as depletion progresses, particular objects persist before the mind and fill the individual's life with uncertainty and apprehension. In business the neurasthenic is afraid to assume any responsibility. In the class-room the pupil is unduly self-conscious and lacks confidence in his own ability; he is timid in the presence of others, and morbidly afraid of possible criticism. In short, the vigor of what we may call personality denoting one's psychic *ensemble*, as it were, is reduced, and this is revealed in the emotional depths as quickly, perhaps more quickly, than in any of the other parts of the being.

It would seem possible to explain these latter phenomena also by the theory of recapitulation. One of the most important and serviceable emotions in the development of the race has been fear, manifested toward a multitude of objects incessantly threatening danger to life and limb. These experiences have left their trace in the nervous organism even of the human species, and each individual must receive them as a heritage in the

[1] See Wilson, Drunkenness, p. 29 *et seq.*
[2] See Mercier, *op cit.*, p. 308 *et seq.*
[3] Loc. cit.
[4] Loc. cit.
[5] Loc. cit.
[6] Loc. cit.

form of "broken reflex arcs"[1] or "rudimentary instincts."[2] In the normal life these reverberations of a remote past are not distinguished because of the strong tone of the higher psychic life; but let this supreme self yield its efficacy at any time and then these recrudescences from phylogenesis well up into consciousness.

Lastly, it may be said, although it scarcely needs argument, that ethical feeling, being a most highly complex social attitude or attunement and a recent *addendum* to the ancestral record, is quickly estranged by whatever disturbs the delicate normal functioning of those material media through which spiritual characteristics are made manifest in this physical world. Collin,[3] Wey,[4] Morrison,[5] Wright,[6] Lombroso,[7] Ribot[8] and Mercier,[9] who have studied moral degeneracy as a social and as an individual phenomenon, have testified in confirmation of the doctrine that moral obliquity is generally the accompaniment of defective physical conditions, and in all probability is the legitimate issue of these. When the highest and most essential cerebral structures become impaired through dissipation of vital energies or improper nutrition, whether due to ignorance, excess, or asceticism, one becomes then a fit instrument for anti-social and immoral impulses; but let him preserve within himself as an individual the vigor of those organs which nature has with unending patience developed in the evolution of the race and he will have a superior chance, to say the least, of adjusting himself in harmonious relations to his social environment.

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[1] Ribot.

[2] Spencer.

[3] *Papers in Penology,* 1891, pp. 27–28.

[4] Ibid., pp. 57–69.

[5] *Juvenile Offenders,* Part II.

[6] American Journal of Neurology and Psychiatry, vols. II and III, pp. 135 et seq.

[7] *Female Offenders.*

[8] *Psychology of the Emotions,* chap. XIV.

[9] *Sanity and Insanity,* p. 308. *et seq.*

CHAPTER II.

CEREBRAL HYGIENE AND ECONOMY IN STUDENT LIFE.

§1. *The Student's Obligations to the State.*—In view of the foregoing it ought not to be necessary to make apologies for urging observation of the laws of cerebral hygiene and economy by the student in his daily life, as a member at present of an educational community, and as a leader of social progress when his preparatory training shall have been completed. But it is not infrequently the case that college youth manifest little interest in that which has the appearance of relating to their immediate well-being, physical, moral, or intellectual; it is indeed esteemed at times to be a mark of superiority to show indifference toward things of this character. It is not apparently believed in a serious manner that the attainment of the highest degree of perfection in respect of all the elements of personality should be the supremest concern of every individual whether within or without the university. But even if a student cannot see that it is a duty he owes to himself to promote in every way possible physical and mental vigor and balance, yet as a factor in the social whole and maintained during his educational career by the state in the hope that he may return to confer blessings upon it, to be a guide in morals and to make less rigorous the struggle for physical existence—these considerations make it obvious that there is absolutely no course left him but to conserve his energies and employ them to the best advantage, that he may repay the obligation due the community that has favored him. In the support of the university the state provides means for a few of its members to receive the benefits of the broadest education; it has then a just right to demand that every individual so favored shall profit by these opportunities to the fullest possible extent. If for any remediable cause, as dissolute living

or excess, causing waste of vital forces, or failure to provide nervous energy equal to the need in profiting by instruction here, a student does not make the most of his privileges, then from the community standpoint such an one is apostate to his plain and simple duty. Being a recipient of the bounty of the commonwealth, his indebtedness to it cannot be gainsaid; and it is a wholly erroneous conception which persists against all reason in some university communities, especially in those sustained at public expense, that a student is not beholden in his conduct to any one but himself and his guardians.

§2. *The Study of Psychical Processes,—Dangers, Advantages.*—It perhaps should be said at this time that, in general, it cannot but prove detrimental to become too greatly concerned about one's own physical or mental processes. One who introspects much for egoistic ends can accomplish but little in this world; thinking all the time about life functions tends to render them abnormal. Nature has evidently designed that for the most part one should be interested in objects and aims outside of self; and the machinery of the organism will run most smoothly when it is left largely to the oversight of subconscious agencies. But while this as a general principle is of superior worth in the practical affairs of life, it yet does not obtain rigidly as it relates to the subject under discussion,—the most frugal and efficient methods of generating and expending nervous energy. Every one knows, to illustrate by a single instance, that in the matter of food, which is the most important factor in the production of vital force, there are great difficulties to be overcome in breaking away from the dogmas and practices of tradition. But recent investigation has made the beginnings at least of a science of nutrition, wherein are set forth the needs of the organism that it may best fulfill its function as an instrument of mind and as a mechanism designed to accomplish a given amount of work, and how these needs may best be met: yet the community at large for whom alone these things are of value, has exhibited little interest in them

thus far. While instinct may be trusted a good way in advising us what and how to eat, yet it is certainly not an infallible guide, especially since it is not within its scope to suggest improved methods of manufacturing foods, and even new kinds of foods themselves. It merely determines sort and quantity when articles are presented, so its sphere of usefulness is quite limited. Again, we tend naturally in most instances to save needless wear and tear of mind and body, yet as we shall see later there are avenues of waste which continue to drain off much of our energies until we get to work consciously to stop them up. In respect to these matters, then, study cannot fail to be of benefit to every person, teaching him how to make the best kind of a machine of himself, so to speak. But when once he learns the trick, his mind may with advantage be turned altogether in other directions; he need not, he must not, be in constant query respecting what he should eat, and how he should work.

But now we are all apt to feel and often to say that we have thus far been steering our barks in a given direction, and considering how the winds have favored us, and what progress we have made, we cannot think we have been on the wrong tack. There seems to lurk within the bosom of every one of us a conviction begotten of the tendency to regard self as the standard of excellence, that we cannot be very greatly improved upon; but this belief, it need scarcely be said, is rarely if ever the result of much reflection upon one's attainments and limitations. While one may find occasion for congratulation that he is as well balanced as he is, and that his energies are devoted as largely as they are to profitable production, yet he needs to recognize, or most of us do at any rate, that we are hindered in a thousand directions by obstacles and restrictions which seriously impair efficiency. Most of us probably have little conception of what a perfect man-machine would be, one who is thoroughly balanced in mind and body, who always has himself well in hand, who has abundant energies for the tasks which lie in his way. One who, looks at life as in a process of evolution, which seems in no wise to be yet com-

plete, sees that in the matter of human perfection (which means nothing more than consummate adjustment to one's social and natural environments) people may be aided in individual cases in attaining thereunto by compliance with the natural laws to which harmonious adjustment is required. This conception leads one to believe in the possibility of continuous improvement, while at the same time holding securely to all that has been accomplished, and being devoutly thankful therefor.

§3. *The Educator's Concern With Cerebral Hygiene.*—Such a bulletin as this would doubtless not be necessary if there were persons in the community whose special interest and duty it was to bring the matters herein discussed in their practical aspects to the attention of the people at large. But there are at present few such persons in any community, and in most places there are none at all. One would naturally suppose that these affairs would lie within the domain of the physician; but as a matter of fact physicians have hitherto been dealing largely if not entirely with disease, with therapeutics, while the thing we are considering is of a wholly different character. One's energies may run out on the debit side for so long a time, without proportionate income on the other side, that hostile forces overpower him; disease seizes upon him, and then the physician seeks to aid him in winning back wasted strength. But it is a far cry from the highest efficiency of mind and body to that disintegrated condition realized in actual disease. One may be living on a low plane so far as the generation and conservation of vital energy is concerned, and yet not come under the eye of the physician. The M. D.'s have not yet dealt largely with the subject of nutrition for healthy beings; and they have only glanced by the way at all the various avenues through which energies are dissipated in prosecuting the work of daily life. Indeed, medicine seeks to cure, not to prevent, nor to raise the general level of organic life. A few medical writers have, however, given these matters some attention,

but it would require little space to enumerate them and tell what they have done.[1]

As things stand at present it falls to the educator to consider some of these physical phenomena which directly determine the fruitfulness of his teaching. It was generally thought in older times when the relation of mind and body was quite differently understood, that the teacher's duty was fulfilled when he simply offered mental aliment to his pupils. If they did not receive and digest it, he sought to aid them in the process by generous stimulation with the cane and the birch.[2] But in our own day an intelligent teacher knows that when his pupil is lacking in available cerebral energy his instruction will be of little avail, either in cultivating the intellect or in fashioning character; and he ascribes shortcomings more often to defective physical conditions than to lethargy or perverseness of the will. He sees then the necessity for considering those factors which inevitably decide whether what he presents will be wrought into the mental structure of his pupil or whether it will simply be an added load to an already overburdened mind,—overburdened because of deficiencies in the neural structures through which it is manifested and by which it is determined.

§4. *Studies at the University of Wisconsin: Purpose and Methods.*—Holding these views the School of Education, at the instance of the writer, sent out to all students in the University of Wisconsin, in the spring of 1898, a questionnaire relating to the subjects discussed in the preceding paragraphs,—the modes of producing cerebral energy and conserving it so that it may as fully as possible be expended in profitable directions. The primary purpose of the questionnaire was to turn the thoughts

[1] The best work with which I am familiar is Stevenson and Murphy, op. cit, 3 vols. This is not adapted, however, for general reading; nor does it devote much attention to mental hygiene and economy. Other good works are Parks: *Practical Hygiene;* Wilson: *Handbook of Hygiene and Sanitary Science;* Rohe: *Text book of Hygiene.* Carpenter's Physiology has some very good hints on hygiene. Martin: *The Human Body,* chaps. XX, XXI, and XXIX discusses in a scientific and practical way some of the problems herein considered.

[2] See a most interesting book,—Cooper: The History of the Rod.

of students to a consideration of the hygiene of food, exercise, ventilation of living and sleeping rooms, the arrangement of the daily program, the use of particular materials in writing, and similar matters of practical importance; and it was hoped in addition to obtain statistical data relating to these affairs which would be of some local, and perhaps also of general interest. The questionnaire, with the explanatory letter, follows:

MADISON, MARCH 5, 1898.

The accompanying circular is sent you in the hope that you may be able to give me some exact information respecting your mode of life in the University. This is not requested for any personal reasons whatever; but it is desired simply to be collated for scientific purposes with similar data gained from other students. In the course in Child-Study much attention is given to the subject of mental hygiene and economy during the period of school and college life; and it is the plan to use the information obtained from the responses to this circular in the regular Child-Study work, and as the basis of a bulletin to be issued later for the guidance of students in respect of the important matters referred to herein. It is the purpose to present in this bulletin the results of research regarding the manner in which one's daily life should be ordered so that he may do the greatest amount of intellectual work with the least expenditure of energy, and without endangering mental health and poise; but in order that local conditions may be made more suitable, if desirable, for student life, it is needful that those conditions be understood just as they exist. I trust, therefore, that you will answer the enclosed questions as fully, and particularly as *accurately*, as possible. If you are not sure in any of your replies, say so. If there are any questions you do not care to answer, omit them; but I wish to assure you that your name will in no case be known to any one but myself and my assistant, and it is recorded simply as a guarantee of earnestness and good faith in the replies. If your answers are referred to for any purpose whatever it will be by number. Please to return the circular in the enclosed envelope as soon as you can conveniently supply the information requested. Drop the envelope in one of the boxes labeled "Child-Study" in Library, University, or Science Hall. Be as complete and detailed in your answers as your knowledge will warrant, using more paper if necessary.

Very respectfully yours,

M. V. O'SHEA.

CIRCULAR.

I. FOOD:

1. Under the headings Breakfast, Luncheon, Dinner, please write in detail what you customarily eat and drink at each meal.

If possible, keep account for a week and indicate number of times each article is eaten; thus: oatmeal, 7; beeksteak, 5, etc.

Be specific regarding the quality of each article, as *bread:* graham, whole wheat, white, rye; *meat:* beefsteak, roast beef, roast chicken, enumerating each separately.

Indicate also, as accurately as possible, in what manner and how thoroughly each article is cooked. Observe particularly whether the meat is boiled, broiled, roasted, or fried; how long the oatmeal and other cereals are cooked, whether over night or only for an hour or two in the morning; whether the bread is light or heavy, etc. (Your landlady will doubtless gladly inform you upon these matters if you ask her, and she will probably be pleased to note your interest in her culinary enterprises.)

2. What articles of food do you like best? What ones really form the substance of your dietary? Do you eat between meals, indulge in midnight lunches, etc.? Do you have dinner at midday or at night?

II. SLEEP:

1. Do you sleep soundly? Dream much? How many hours do you plan to spend in sleep? How late do you study at night? When do you go to bed? What time do you arise in the morning?

2. Have you ever studied all night, or nearly so? What effect did it have upon you? Has knowledge gained at such time been enduring?

III. STUDY:

1. How many hours per day? What are your study hours? Are they regular and uninterrupted, or otherwise? How many hours may you count upon with certainty to be entirely uninterrupted during the day? During what hours of the day are you at your best? When are you dullest? Do you stimulate yourself artificially to study? If so, how?

2. Indicate the amount of time you spend upon each of your studies? How many hours of written work each day? Pen or pencil? If pen, fine or blunt point? Metal holder? If pencil, soft or hard?

IV. HEALTH:

1. Headaches? Indigestion? Colds?
2. Have you had your eyes examined by a skilled oculist?
3. Indicate time spent by you in gymnasium; in open air.
4. Do you dance? How frequently? How late?
5. Do you smoke? Cigars, Cigarettes or Pipe?

V. IN GENERAL:

What do you pay for board? For room? How large a room have you? How many in it? How heated? How ventilated? Do you board yourself? Do you do your own washing? How much work, manual or otherwise, do you undertake outside of your University duties?

A few words respecting the distinct purpose of this study and the method of its prosecution should be added here. In the first place, it was fully realized that it would not be possible to obtain a great body of accurate, scientific information by this method, especially in regard to the subject of food, in respect either of quantity, quality, or the character of its preparation for utiliza-

tion in the organism. No effort was made to ascertain how much food was eaten, for the reason principally that such a request could not be complied with; and this information was not particularly desired anyway since there was no intention of enquiring in minute detail into local practices because of the vast amount of labor it would entail without being of great value. What was wanted was a general statement of the articles of food which form the substance of students' dietaries; and it was thought to be sufficiently definite for the purposes of the study to assume that the amount and quality of the articles consumed would be such as have been commonly found to be the case elsewhere. Regarding the subject of cooking, it was not hoped that exact data could be obtained, since it would be difficult for students to determine this with absolute accuracy. It was thought, however, that some reliable impression could be gained, especially of the cooking of starchy foods and of the especial manner of preparing meats. The results have realized all that was antici pated, although in some instances the answers were for the most part useless except as they could be interpreted from other papers that were written by students living under similar conditions,—obtaining their food at the same table, for example, and dwelling in the same house. In the interpretation of data the writer makes use of his own observations gained while visiting several boarding clubs and restaurants. His experience, it may be added here, has substantially corroborated the results obtained from the questionnaire.

The data furnished in response to questions relating to exercise, habits of eating with respect to hours and irregularities, the size, heating, and ventilation of living rooms, the arrangement of the daily program, the employment of writing materials and the like, are more complete and definite and are reasonably satisfactory. The information respecting health, however, is probably only in a relative way of value, since students are not able to observe such matters with scientific accuracy; and they, in common with other people, are not good judges of their own status in this regard anyway, since they have no standard for measurement except their own expe-

riences, which are too apt to represent to them normal conditions, however far they may be from this. It was expected, though, that the data here would be valuable only in a general way as indicating instances of important abnormal conditions which interfere with the efficiency of the individual's work.

While it was hoped to gain from the investigation some reliable estimate of the energeic aspects of student life in our community, yet the primary object after all in asking students to report the practices of their daily lives was (and this has been already said) to direct their attention to a few of these vital things in the belief that this in itself would serve to correct some wasteful habits. It was thought it would be of value, also, to suggest to students the necessity of intelligently arranging their dietaries so far as they could control the matter, with the purpose in view to provide the largest amount of energy at the least expense, whether regarded from the point of view of the effort required to transform certain foods into nervous force, or of the apparently more practical aspect of the financial outlay. This expectation has been realized in a measure at least, since there has come to the writer trustworthy evidence that the questionings of students in regard to the articles of food and cooking has resulted in some improvement in both directions. It was believed, finally, that this would be a good way in which to prepare the minds of students for the discussion of the subject of mental economy, which is the *raison d'etre* of this bulletin.

The labor of collating the returns was so great that it was found impossible to examine but 316 papers.[1] Care was taken, however, to select those which represented customs and practices in the different phases of university life, and it is doubtful if there would have been any special advantage in the examination of a much larger number; the conclusions regarding local manners and methods would probably not have been materially altered therebv .

[1] The statistical part of the work was done under my direction by Mr. F. J. Wojta.

CHAPTER III.

RELATIVE VALUE OF FOODS IN THE PRODUCTION OF NERVOUS ENERGY.

§1. *Philosophy of Nutrition.*—It is no doubt known to every one that the primary function of food in the system is to supply the force or forces required for the maintenance of the activities of life. The organism may be considered from this point of view as a mechanism designed to accomplish a certain amount of work, physical or mental; and in effecting this the energy represented in the thing done, including all accessory expenditures and waste, must balance that expended by the doer, thus conforming to the principle of the conservation of energy. The work thus required to be performed by every organism and entailing dissipation of vital energy may be regarded as of two kinds; in the first place the body must be kept up to a temperature quite above that of the environment in which it is ordinarily placed, and a large amount of force must therefore be transformed into heat. Then there is in every instance, though differing with different people, a characteristic amount of energy employed in muscular and mental activity. In these two directions force is being constantly utilized, and it must be as constantly replenished by the processes of nutrition if life is to be maintained

The factor of heat seems to be a practically uniform one for all people, since if in any case the body fall far below a certain standard the delicate adjustments essential for the perpetuation of the organism are disturbed and physical annihilation ensues. And by virtue of a comprehensive law of being, whereby all possible effort will be made to prevent the dissolution of life, the organism will strive in every way to supply the necessary energy for the preservation of normal

temperature; and when needed it will draw upon the credit of the muscular and nervous systems, since one can survive with a relatively small amount of either motor or mental action. When, then, it may be remarked by the way, the body is not properly protected in cold climates, the energy which is generated in the system will be dissipated in comparatively large ratio in the effort to keep warm; and, as a consequence, less force can be utilized in the kinds of work for which in reality the organism exists; for in the highest forms of life, whatever may be true of those lower in the scale of existence, the ultimate purposes of existence are very clearly of a mental order. And in the attainment of these, motor processes are for the most part essential. So that in man mental and motor activities are of primary importance, regarded from the point of view of the *raison d'etre* of the organism, as well as from the testimony of introspection and of the desires of the human heart.

In addition to the purposes of nutrition already indicated there should be mentioned one other. In a growing structure, where continual increase in size and weight is taking place, there are required nutritive substances other than those utilized in carrying forward somatic and psychical functionings. There are needed substances for augmenting the bulk of bone and nerve and muscle,—materials for construction, that is to say. In adult life, however, when growth has been completed, there is no longer a demand for materials to build up, but only to repair the wear and tear of mind and body; so that in maturity we may take account principally of the requirements of the organism for the generation of force employed in the prosecution of mental and motor enterprises.

To return to our first proposition, the energy demanded to sustain the activities of life must be supplied in the food stuffs which are eaten. Now it is probably well known that various food elements are required to meet the different needs of body and brain. The nutrients best suited to furnish the materials employed in making bone and muscle are not alone sufficient to

promote either muscular or mental action; and those adapted to supply physical power in largest measure are not in all cases the ones from which to gain cerebral energy most advantageously, as will be demonstrated more fully later. It should be noted here, however, that we say *just the ones,* for in some degree the energy of the entire organism may on occasion be drawn upon for the maintenance of either mental activity, motor activity, or temperature. This is indicated in the fact that arduous manual labor lessens the vigor, keenness, and duration of intellectual processes,[1] and reduces the temperature of the body. And in the same way intense and long continued mental application reduces the power of motor execution,[2] and, as in muscular labor, makes heavy demands upon the calorific condition of the system.[3] Spencer[4] called attention to this some time ago, and insisted that excessive brain work was causing physical deterioration in the English people. Mosso[5] maintains that severe brain work makes so great a demand upon the energies of the body that the muscles sacrifice a part of their albuminous constituents that mental activity may be sustained.

And yet there is a limit to the convertibility of the energies of the organism. One may be in good flesh and yet be undernourished nervously. Warner,[6] in his inspection of the school children of London, has frequently found instances where there was every evidence of adequate bodily nourishment, and yet nerve signs revealed a depleted condition of the brain. A few years ago there came under my observation in the city of Buffalo two children who gave their teachers and parents much trouble on account of their irritability and the slow progress they made in their studies. They appeared outwardly to be well nourished; but finally upon expert examination it was

[1] Curtis, Pedagogical Seminary, Vol. VI. VI, No. I, p. 78, quotes Mosso as saying that he has several times climbed to the top of Mount Blanc, but he can remember nothing of the view. He has a friend who has to write down his impressions on his way up or he can retain nothing.

[2] Mosso loc. cit.

[3] See an instance of lack of sleep causing marked fall in temperature. Pedagogical Seminary, Vol. VI, No. 1, p. 81.

[4] *Education*, p. 260 et seq.

[5] Loc. cit.

[6] *Mental Faculty*, pp. 79–80.

found that the blood was deficient in the elements required for adequate cerebral nutrition, and a special diet was resorted to. In a few weeks the children had noticeably improved in their emotional activities and in their intellectual work.

While, then, the production of energy for mental activity is, for the most part, simply one phase of the general problem of generating force for all the needs of the organism—the brain drawing its quota out of the common stock—yet in some measure this demands particular consideration. At the same time we must recognize with Warner,[1] that one probably never finds a vigorous brain in a starved body; so that in aiming to produce cerebral energy we must see to it that the organism *in toto* is well provided for, which requires that we consider the subject of nutrition as a whole.

It seems almost superfluous to say that the ideal dietary is one which will just meet the needs of the organism; it will not supply more nor less nutrition than can be profitably utilized. Overeating results in burdening the system, and so limiting its efficiency; undereating fails to supply fuel enough to keep the machinery of life in motion. There should indeed hang over each man's table the motto, "Eat to live, so that every power will be at its best;" and if this be made the rule of life one's board will afford the foods which his occupation specially demands. If he be an outdoors-man he must have more constructive and calorifacient material than if he live a sedentary life. If he be a student, fond of vigorous physical exercise for a few hours during the day, he will need to make more prominent in his dietary the reparative and heat-affording foods than will his lethargic, inactive classmate. When these individual needs are not recognized and the same regimen is provided for all with little opportunity for selection, then plainly some must suffer; there will be those who will be either overfed or underfed.

It has already been indicated that different food-stuffs contain different nutritive elements, and in order to secure proper nutrition they must be combined with one another in such a man-

[1] Op. cit., p. 79.

ner as to preserve right proportions between them in ministering to the needs of the organism, no matter whether we depend upon appetite, chemical analysis, or custom as our guide; a point which will receive fuller discussion in another place. The principal constituents of foods are: fats, carbohydrates, albumen (or protein), and salts;[1] and the uses to which each of these are put in building up, repairing, and sustaining mental and motor activity are satisfactorily stated by Church,[2] whose treatment of the subject may here be adopted.

CLASS I.—NUTRIENTS.

Division 1.—Incombustible Compounds.

Group i. Water—The carrier of nutritive materials and waste products; forms an essential part of all tissues; is present in large proportion where change is most active.

Group ii. Salts or Mineral Matter, such as common salt and phosphate of lime, which serve to effect changes and build up certain tissues.

Division 2.—Combustible Compounds.

Group iii. Carbon Compounds, such as starch, dextrin, sugar, and fat, which serve to keep up the heat and movements of the body by the discharge of their potential energy during oxidation in the organism. The fat of the body is formed in part from fat or oil in the food. The members of this group are often called "heat-givers," a term which is equivalent to "force-producers."

Appendix to Group iii. Gum, mucilage, and pectose, approach starch in chemical composition, and probably serve the same end. Cellulose may be named here, but its value as a nutrient is doubtful.

Group iv. Nitrogen Compounds, such as albumen, myosin, and casein, the chief formative and reparative compounds of food; they also may yield fat, and by their oxidation set free heat and motion. They are often named "flesh-formers," while the group is known as albuminoids.

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[1] Martin, Human Body, chap. XXI, employs a more detailed classification, but it is common now among writers on dietetics to speak only of the four great classes of nutritive elements, and this will be deemed sufficiently detailed for our purposes.

[2] *Food*, p. 9, (London, 1889, Chapman and Hall).

Appendix to Group iv. The ossein of bones and gelatin; cartilage and chondrin; keratin and elastin from skin and connective tissue,—approach the albuminoids in composition, and may serve in a measure, some of the same purposes in the body as those to which the true albuminoids are applied. This series of compounds may conveniently be designated the osseids.

CLASS II.—FOOD ADJUNCTS.

Group i. Alcohol, as contained in beers, wines, and spirits.

Group ii. Volatile or Essential Oils, and other odorous and aromatic compounds, as contained in condiments, like mustard and pepper, and in spices, as ginger and cloves.

Group iii. Acids, as citric acid in lemons, malic in apples, tartaric in grapes, oxalic in rhubarb, and acetic in vinegar and pickles.

Group iv. Alkaloids, as caffeine in coffee and tea, theobromine in cocoa, and nicotine in tobacco.

§2. *Statistical Summary of Studies on Foods.*—With this word upon the subject of nutritive values in general the returns from the questionnaire relating to food may be presented. The figures denote the number of times the various dishes were eaten, in a single week, and indicate simply the *relative* frequency with which certain articles of food are found in our students' dietaries. From an examination of the tables and individual diet lists it will become evident, and this is a point worth noting early, that brain workers in our community have set before them substantially the same bills of fare that manual laborers do, or that they discussed themselves when they were upon the farm, living an active out-door life.

The different articles of food arranged according to their relative frequency in dietaries are given below. The returns do not indicate the precise days of the year upon which records were made; but it may be sufficiently definite to know that the blanks were distributed on March 23, and were all returned by April 27:

Breakfast.

Kind of Food.	No. Times Served.	Kind of Food.	No. Times Served.
1 Oatmeal	1,380	14 Porksteak	233
2 Bread, white	1,189	15 Rice	145
3 Coffee	1,088	16 Pie	104
4 Eggs, fried	812	17 Biscuits, white	78
5 Fruit	757	18 Mutton	78
6 Butter	752	19 Fish	73
7 Milk	704	20 Tea	62
8 Beefsteak	677	21 Veal chops	59
9 Potatoes, fried	646	22 Corn cake	58
10 Potatoes, baked	586	23 Potatoes, mashed	52
11 Toast	536	24 Sausage	38
12 Graham, bread	442	25 Eggs, poached	27
13 Pancake	298	26 Rye, bread	12

Dinner.

Articles of Food.	No. Times Served.	Articles of Food.	No. Times Served.
1 Bread, white	1,067	18 Corn	199
2 Milk	844	19 Cranberries	195
3 Vegetables	716	20 Eggs, fried	188
4 Potatoes, fried	700	21 Peas	183
5 Fruit	688	22 Tea	182
6 Bread, graham	683	23 Potatoes, mashed	176
7 Pie	604	24 Veal, boiled	172
8 Roast beef	588	25 Beefsteak	164
9 Roast pork	440	26 Preserves	150
10 Pudding	431	27 Fish, fried	149
11 Cake	375	28 Mutton	147
12 Coffee	356	29 Ice cream	131
13 Sauce	333	30 Cheese	127
14 Potatoes, baked	238	31 Crackers, soda	115
15 Roast chicken and turkey	219	32 Salmon	88
16 Soup	215	33 Tongue	54
17 Beans	200	34 Oysters	41

Luncheon.

	Articles of Food.	No. Times Served.		Articles of Food.	No. Time Served.
1	Bread, white	913	19	Biscuits	217
2	Potatoes, fried	660	20	Pudding	186
3	Milk	650	21	Crackers, soda	186
4	Cake	636	22	Toast	186
5	Bread, graham	594	23	Sausage	180
6	Potatoes, baked	552	24	Chocolate	174
7	Sauce	535	25	Oysters	174
8	Fruit	516	26	Chicken and turkey	172
9	Vegetables	468	27	Soup	166
10	Cold ham	417	28	Fish	160
11	Eggs, fried	402	29	Strawberries	155
12	Tea	401	30	Potatoes, mashed	155
13	Butter	389	31	Mutton	134
14	Coffee	338	32	Ice cream	131
15	Roast beef	255	33	Roast pork	111
16	Pie	253	34	Tongue	63
17	Beefsteak	247	35	Honey	17
18	Preserves	222			

Samples of the bills of fare served in the various places where students obtain meals are offered to show individual differences, and to be used later in computing the nutrient value of these typical rations.

Club Board—Questionnaire No. 1101.

Breakfast.		Luncheon.		Dinner.	
Oatmeal	4	Potatoes, fried	7	Meats—Chicken, roast	1
Pounded wheat	2	Hash	2	Beef, boiled	3
Coffee	7	Beef, boiled	3	Pork, boiled	2
Pork, fried	3	Veal, fried	2	Veal	1
Roast beef	4	Milk	7	Potatoes, boiled	7
Eggs and ham	1	White bread	7	Lettuce	4
White bread	5 or 6	Cake and sauce	4	Cabbage, boiled	3
Graham bread	2	Cabbage, boiled	3	Bread, white	3 or 4
Potatoes	2 or 3	Fried eggs	3	Corn, boiled	3
Milk	2 or 3	Butter	7	Milk	7
Wheat flour cakes	1	Strawberry shortcake	3	Pie	5
				Pudding	2
				Biscuits and honey	2

Private Board—No. 1526.

Breakfast.		Luncheon.		Dinner.	
Oatmeal, cooked 20 minutes.		Wiener wurst.		Bread and butter.	
Beefsteak	4	Milk.		Sugar.	
Pancakes	1	Fried Pork.		Corn.	
Bread and butter.		White bread.		Lamb	1
Milk, Water.		Sauce.		Mutton	1
Sugar.		Cake.		Chicken	1
Salt.		Eggs, occasionally.		Soup	1
Mustard.		Sauerkrout.		Tomatoes, occasionally.	
		Butter.		Sugar.	
		Lettuce, occasionally.		Salt.	
		Water.		Pepper.	

Restaurant—No. 1440.

Breakfast.		Luncheon.		Dinner.	
Oatmeal	7	Potatoes	7	Soup	2
Biscuits	7	Coffee	7	Boiled beef	6
Wheat bread	7	Cold beef	2	Fish	1
Eggs	3	Eggs	2	Potatoes	7
Pancakes	1	Hash	1	Gravy	7
Coffee	7	White bread	7	White bread	7
Sugar	7	Graham bread	4	Brown bread	5
Roast pork	2	Rye bread	3	Rye bread	3
Roast beef	2	Sugar	7	Pie	5
Graham bread	2	Butter	7	Beans	1
Fried cakes	3	Apples	3	Kraut	1
Potatoes	7	Bananas	3	Tomatoes, boiled	2
Butter	7	Oranges	1	Parsnips	1
				Cheese	1
				Lettuce	1

Ladies' Hall—No. 1027.

Breakfast.		Lnncheon.		Dinner.	
Coffee	7	Milk toast	1	Parsnips, fried	7
Toast	5	Cold beef	1	Pickles	3
Potatoes, fried	2	Chicken, cold	1	Boiled beef	1
Beefsteak, fried	2	Ham	1	Beefsteak, fried	3
Ginger bread	2	Cheese	1	Lettuce	1
Sauce	1	Strawberries	2	Tomatoes	1
Eggs, poached	1	Cake	5	Pie	1
Donghnuts	1	Tongue	1	Cheese	1
		Potatoes, fried	2	Canned peas	1
		Radishes	1	Chicken, fried	2
		Honey	1	Sauce	3
		Milk	7	Potatoes, boiled	1
		Sauce	7	Bread	2
		Hot breads	3	Butter	7
		Cold breads	4	Ices and creams	2
		Olives	1	Cake	2
		Chocolate	7	Pudding	2
		Butter	7	Fruit and cream	1
		Corn	1	Beans	1
				Onions	1

Meats not very well done. Bread neither heavy nor light, but rather medium.

The articles of food which are actually eaten most largely are indicated in the answer to the question, What foods really form the substance of your dietary? One hundred and nine answered meats and vegetables, without specifying the kinds of each. Eighty-five live principally on oatmeal, according to the returns; 85 on bread and butter; 80 on potatoes; 71 on eggs; 76 on roast beef.

§3. *Composition of the Food-stuffs Found in the Tables.*—In order to pass judgment upon the value of these dietaries, either as a whole or individually, it is necessary to know what nutritive ingredients the various articles mentioned afford. It is doubtless impossible to determine this exactly by any known methods

of calculation, since the element of life in general and individuality in particular,[1] which cannot be precisely reckoned with in our present methods of scientific experiment, probably modify in some measure the value of a food as it might appear when subjected to chemical examination. But chemical analysis can ascertain with accuracy the composition of any food, and this has been relied upon for a long time as a measurably safe index to the worth of any article. It is certainly not an overstatement to say that it is a reasonably reliable and serviceable method of determination. Granting an unknown and indeterminable factor in estimating the nutritive value of any food, yet chemical analysis would enable us to say this much at least,—that there are certain things in which it would be impossible, considering the limitations of the human digestive apparatus, to get sufficient albuminous elements, for instance, to support active, vigorous life; while in others, if eaten exclusively or even largely, albumen would be gained in excess. In this way, though the formulas obtained from chemical analyses do not represent the exact value of milk, for instance, as it will be received by the stomachs of different persons, yet, to repeat, it does indicate the substances from which the several elements may be derived most easily and economically, and this will give enough play to individual preferences and idiosyncrasies in digestion and assimilation. It should be said, too, that while the organism requires a certain quantity of fats, carbohydrates, and albumen, yet the administration of these in pure form would not serve to properly nourish a person. The nutrition which they contain is yielded only when they are obtained in an organized state as they are found in nature in the fruits, seeds, etc., of plants and in the flesh of animals.

The composition of foods as given by various investigators, while differing in some cases in slight degree, are yet for all practical purposes identical. The most satisfactory analyses

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[1] Charts showing differences between individuals in digestive characteristics, for instance, are shown further along, in Chap. VI.

with which the writer is familiar are those made by Jordan,[1] Atwater,[2] Church,[3] Smith,[4] and Kellogg.[5] The tables by Atwater are given below:

Food Materials.	Refuse (bones, skin, shell, etc.).	Edible Portion.						
		Water.	Nutrients.					Fuel value of 1 pound.
			Total	Protein.	Fat.	Carbohydrates.	Mineral matters.	
Animal foods, as purchased.	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Cal.*
Beef:								
Neck	20	49.6	30.4	15.6	14	....	.8	880
Shoulder	12.6	55.8	31.6	17	13.7	....	.9	895
Chuck rib	14.6	49.5	35.9	15	20.1	....	.8	1,125
Rib	21	38.2	40.8	12.2	27.9	....	.7	1,405
Sirloin	19.5	48.3	32.2	15	16.4	....	.8	970
Round steak	7.8	60.9	31.3	18	12.3	....	1	855
Side, without kidney fat	19.2	44.3	36.5	13.9	21.8	....	.8	1,180
Rump, corned	5	70.8	24.2	16.7	5.1	....	2.4	525
Flank, corned	12.1	43.7	44.2	12.4	29.2	....	2.6	1,460
Veal, shoulder	17.9	56.7	25.4	16.6	7.9	....	.9	640
Mutton:								
Shoulder	16.3	49	34.7	15.1	18.8	....	.8	1,075
Leg	18.1	50.6	31.3	15	15.6	....	.7	935
Loin	15.8	41.5	42.7	12.6	29.5	....	.6	1,480
Side, without kidney fat	17.3	44.2	38.5	14	23.7	....	.8	1,260
Pork:								
Shoulder roast, fresh	14.6	43	42.4	13.6	28	....	.8	1,435
Ham, salted, smoked	11.4	36.8	51.8	14.8	34.6	....	2.4	1,735
Chicken	38.2	44.6	17.2	15.1	1.2	....	.9	330
Turkey	32.4	44.7	22.9	16.1	5.9	....	.9	550
Eggs, in shell	13.7	63.1	23.2	12.1	10.2	....	.9	655
Fish, etc.:								
Flounder, whole	66.8	27.2	6	5.2	.3	....	.5	110
Bluefish, dressed	48.6	43	11.1	9.8	.6	....	.7	210
Codfish, dressed	29.9	58.5	11.6	10.6	.2	....	.8	205
Shad, whole	50.1	35.2	14.7	9.2	4.8	....	.7	375
Mackerel, whole	44.8	40.4	15	10	4.3	....	.7	365
Halibut, dressed	17.7	61.9	20.4	15.1	4.4	....	.9	465
Salmon, whole	35.3	40.6	24.1	14.3	8.8	....	1	635
Salt codfish	42.1	40.5	17.6	16	.4	....	1.2	315
Smoked herring	50.9	19.2	29.9	20.2	8.8	....	.9	745
Salt mackerel	40.4	28.1	31.5	14.7	15.1	....	1.7	910
Canned salmon	4.9	59.3	35.8	19.3	15.3	....	1.2	1,005
Lobsters	62.1	31	6.9	5.5	.7	.1	.6	135
Oysters	82.3	15.4	2.3	1.1	.2	.6	.4	40

[1] Jordan: *Dietary Studies at the Maine State College in 1885*, published by Washington Government Printing Office.

[2] Atwater: *Foods: Nutritive Value and Cost*, Washington Government Printing Office.

[3] Church: *Food*, Chapman and Hall, London.

[4] Smith: *Foods*, D. Appleton & Co., New York.

[5] Kellogg: *Publications of the Laboratory of Hygiene of the Battle Creek (Mich.) Sanitarium.*

Composition of foods—continued.

Food Materials.	Refuse (bones, skin, shell, etc.).	Edible Portion.						
		Water.	Nutrients.					Fuel value of 1 pound.
			Total	Protein.	Fat.	Carbohydrates.	Mineral matter.	
Animal foods, edible portion.	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Cal.*
Beef:								
Neck	......	62	38	19.5	17.5	....	1	1,100
Shoulder	......	63.9	36.1	19.5	15.6	....	1	1,020
Chuck rib	......	58	42	17.6	23.5	....	.9	1,320
Rib	......	48.1	51.9	15.4	35.6	....	.9	1,790
Sirloin	......	60	40	18.5	20.5	....	.1	1,210
Round	......	68.2	31.8	20.5	10.1	....	1.2	805
Side, without kidney fat	......	54.8	45.2	17.2	27.1	....	.9	1,465
Rump, corned	......	58.1	41.9	13.3	26.6	......	2	1,370
Flank, corned	......	49.8	50.2	14.2	33	....	3	1,655
Veal, shoulder	......	68.8	31.2	20.2	9.8	....	1.2	790
Mutton:								
Shoulder	......	58.6	41.4	18.1	22.4	....	.9	1,280
Leg	.....	61.8	38.2	18.3	19	....	.9	1,140
Loin	......	49.3	50.7	15	35	.. ..	.7	1,755
Side, without kidney fat	......	53.5	46.5	16.9	28.7	....	.9	1,525
Pork:								
Shoulder roast, fresh	......	50.3	49.7	16	32.8	....	.9	1,680
Ham, salted, smoked	......	41.5	58.5	16.7	39.1	....	2.7	1,960
Fat, salted	......	12.1	87.9	.9	82.8	....	4.2	3,510
Sausage:								
Pork	......	41.5	58.8	13.8	42.8	....	2.2	2,065
Bologna	......	62.4	37.6	18.8	15.8	....	3	1,015
Chicken	......	72.2	27.8	24.4	2	....	1.4	540
Turkey	......	66.2	33.8	23.9	8.7	....	1.2	810
Eggs	......	73.8	26.2	14.9	10.5	....	.8	721
Milk	......	87	13	3.6	4	4.7	.7	325
Butter	......	10.5	89	1	85	.5	3	3,615
Oleomargarine	......	11	89.5	.6	85	.4	3	3,605
Cheese:								
Full cream	......	30.2	69.8	28.3	35.5	1.8	4.2	2,070
Skim milk	......	41.3	58.7	38.4	6.8	8.9	4.6	1,165
Fish:								
Flounder	......	84.2	15.8	13.8	.7	....	1.3	285
Haddock	......	81.7	18.3	16.8	.3	....	1.2	325
Codfish	......	82.6	17.4	15.8	.4	....	1.2	310
Shad	......	70.6	29.4	18.6	9.5	....	1.3	745
Mackerel	......	73.4	26.6	18.2	7.1	....	1.3	640
Halibut	......	75.4	24.6	18.3	5.2	....	1.1	560
Salmon	......	63.6	36.4	21.6	13.4	....	1.4	965
Salt cod	......	53.6	......	21.4	.3	....	1.6	410
Herring, salt	......	34.6	......	36.4	15.8	....	1.5	1,345
Mackerel, salt	......	43.4	......	17.3	26.4	....	2.6	1,860
Oysters	......	87.1	12.9	6	1.2	3.7	2	230

Composition of foods—continued.

Food Materials.	Refuse (bones, skin, shell, etc.).	Edible Portion.						
		Water.	Nutrients.					Fuel value of 1 pound.
			Total	Protein.	Fat.	Carbohydrates.	Mineral matter.	
Vegetable foods.	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Pr ct.*	*Cal.*
Wheat flour	......	12.5	87.5	11	1.1	74.9	.5	1,645
Graham flour (wheat)	......	13.1	86.9	11.7	1.7	71.7	1.8	1,625
Rye flour	......	13.1	86.9	6.7	.8	78.7	.7	1,625
Buckwheat flour	......	14.6	85.4	6.9	1.4	76.1	1	1,605
Oatmeal	......	7.6	92.4	15.1	7.1	68.2	2	1,850
Corn meal	......	15	85	9.2	3.8	70.6	1.4	1,645
Rice	......	12.4	87 6	7.4	.4	79.4	.4	1,630
Peas	......	12.3	87.7	26.7	1.7	56.4	2.9	1,565
Beans	......	12.6	87.4	23.1	2	59.2	3.1	1,615
Potatoes	......	78.9	21 1	2.1	.1	17.9	1	375
Sweet potatoes	......	71.1	28.9	1.5	.4	26	1	530
Turnips	......	89.4	10.6	1.2	.2	8.2	1	185
Carrots	......	88.6	11.4	1.1	.4	8.9	1	200
Onions	......	87.6	12 4	1.4	.3	10.1	.6	225
String beans	.....	87.2	12.8	2.2	.4	9.4	.8	235
Green peas	......	78.1	21.9	4.4	.6	16	.9	405
Green corn	......	81.3	18.7	2.8	1.1	13.2	.6	345
Tomatoes	......	96	4	.8	.4	2.5	.3	80
Cabbage	......	91.9	8.1	2.1	.3	5.5	1.1	155
Apples	......	83.2	16.8	.2	.4	15.9	.3	315
Sugar, granulated	......	2	98	......	......	97.8	.2	1,820
Molasses	......	24.6	75.4	......	......	73.1	2.3	1,360
White bread (wheat)	.....	32.3	67.7	8.8	1.7	56.3	.9	1,280
Boston crackers	......	8.3	91.7	10.7	9.9	68.7	2.4	1,895

§4. *Composition and Value of Food Materials Not Found in the Dietary Lists.*—In addition to the composition of articles given in Atwater's tables should be mentioned that of other valuable foods. And we may look first at the familiar edible nuts which are sometimes found upon the tables of the well-to-do, but are generally regarded as a luxury suited to gratify the palate but not well adapted to sustain the activities of body or brain. The chemical composition of these nuts shows, however, that they are exceedingly rich in substances needed for the proper nutrition of the entire organism. The following analyses of these varieties of nuts which are easily obtained in our locality are taken from Church:[1]

[1] Op. cit.

Chemical composition of nuts.

	Parts in 100	In 1 pound.	
Composition of Chestnut-Kernels:		*Oz.*	*Gr.*
Water	14.0	......	......
Albuminoids, etc	8.5	......	......
Starch	29.9	......	......
Dextrin	22.9	......	......
Sugar	17.5	......	......
Oil	1.3	......	......
Cellulose	3.3	......	......
Mineral matter	2.6		
Walnut Kernels:			
Water	44.5	7	53
Albuminoids	12.5	2	0
Mucilage, etc	8.9	1	185
Oil	31.6	5	24
Cellulose	0.8	0	56
Mineral matter	1.7	0	119
Filbert-Kernels:			
Water	48.0	7	297
Albuminoids	8.4	1	151
Oil	28.5	4	245
Mucilage, starch, etc	11.1	1	340
Cellulose	2.5	0	175
Mineral matter	1.5	0	105
Sweet Almonds (shelled):			
Water	6	0	420
Albuminoids, etc	25	4	0
Oil	54	8	280
Mucilage, etc.	9	1	192
Cellulose	3	0	210
Mineral matter	3	0	210
Pistachio-kernels:			
Water	7.4	1	80
Albuminoids, etc	22.7	3	277
Oil	51.1	8	77
Mucilage, etc.	13.0	2	35
Cellulose	2.5	0	175
Mineral matter	3.3	0	231
Cocoanut-kernels:			
Water	46.7	7	200
Albuminoids, etc.	5.5	0	385
Oil	35.9	5	325
Sugar, etc	8.1	1	130
Cellulose	2.9	0	203
Mineral matter	1.0	0	70
Ground or Pea Nuts (shelled):			
Water	7.5	1	87
Albuminoids, etc	24.5	3	403
Starch, etc	11.7	1	382
Oil	50.0	8	0
Cellulose	4.5	0	315
Mineral matter	1.8	0	126

Doubtless one reason why nuts do not constitute a more important part of our dietaries is found in the fact that they are all difficult of digestion by most people, while some of them, as the peanut in the form in which we ordinarily obtain it, are quite invulnerable to the attack of many stomachs. This objection need not longer be urged, however, since methods of preparing

nuts have become so perfected that products are now on the market which will not trouble the most delicate digestive apparatus, and which are at the same time highly nutritious. These preparations present the nutritive elements in nuts in a variety of forms, most of them resembling closely in general appearance and consistency the products of milk. The terms given the different varieties indicate this,—nut butter, nut cream, and the like. The composition of the nut foods manufactured at Battle Creek, Mich., are given below:

	Proteids.	Fats.	Carbo-hydrates.
Malted Nuts	23	20.4	49.3
Nut meal	26	52	19
Nut butter	24	52	19
Bromose	19.6	24	39.4
Maltol	0	20	75

From an economical standpoint they probably furnish more nutrition for money expended than meat and butter, as substitutes for which in whole or in part they are especially well adapted. They are highly esteemed by some hygienists, notably by Kellogg, since, it is said, they furnish the necessary fat in a better form than it can be obtained in butter, or any animal fat which has become separated from the elements with which it is ordinarily combined. It is maintained by these authorities that butter cannot be assimilated in the condition in which it is eaten, but has to be converted back into cream, that is emulsified, before it can be utilized in the system. There is involved here a general principle of nutrition which has been alluded to elsewhere,—that elementary substances in the pure state cannot be incorporated into the system, while they can without trouble when organized in the natural way in plant or animal life. But however this may be it is certain at any rate that the nut products afford palatable and at the same time exceedingly nutritious and readily assimilable articles of food; and they might well have a prominent place in a student's dietary since it is of

the greatest importance that he should, particularly in the morning meal, gain abundant nutrition in the readiest and most agreeable way possible.

There are other food materials which should be mentioned in this place before passing to consider the nutrient values of the dietaries appearing in our statistical summary. These are, in the first place, the preparations of grains wherein a certain proportion of the carbohydrate ingredients have been removed and all or most of the albuminous elements retained. Some of them are known in the market as Granola, Granose, Malt Breakfast Food, Ralston Breakfast Food, Purina, Health Flour, et al. The composition of these foods shows that they contain a higher percentage of proteid elements than the flours and breads presented in Atwater's tables.

Hoffman, chemist at the State Agricultural and Mechanical College of South Carolina, has analyzed Purina Health Flour, and found that it contained:

Water	14 0 per cent.
Proteids	14.9 per cent.
Carbohydrates	66.2 per cent.
Fat	1.6 per cent.
Fibre	1.6 per cent.
Mineral matter	1.7 per cent.

An analysis of Malt Breakfast Food, made by the government chemists at Washington, under the direction of Prof. H. W. Wiley, gives the following:

Proteids	11.63
Carbohydrates	77.00
Fats	1.75
Ash	1.05
Water	7.85
Lignose and cellulose	.73

Germos, as analyzed by the manufacturers, contains 20 per cent. of albumen, 1.5 per cent. of fat, 62 per cent. of starch, and 1 per cent. of salts. Granola is said to contain a still higher percentage of albumen, although I have not been able to secure an analysis showing its exact composition. Granola and Malt Breakfast Food are distinguished in another way, in that the starch they contain is partially digested during the process of

manufacture by the application of heat in the first case and by malting in the second, which convert it into certain varieties of dextrin, a point which will be considered more fully later in discussing the modes of preparing food. This predigestion of the starch renders such foods much more palatable and delicious than the ordinary uncooked article. It may be remarked here, too, that in view of the fact that the ease with which a food can be made to yield the energy it contains is perhaps the most important factor in the determination of its nutritive value, at least for one engaged in mental labor, it can be seen that the foods just mentioned are far superior to those generally found in the dietary lists of our students.

§5. *The Nutrient Value of Student's Dietaries,—Estimates and Comments.*—What now about the dietaries submitted in response to our questionaire? In order to determine their value in a complete and scientific manner one should have ascertained the precise quantity of each dish eaten, its exact composition, and the digestive peculiarities of each individual; and these data could be obtained only with great difficulty, if indeed they could be secured at all. But (and this has been said already) there was at the outset no intention of making an elaborate and detailed study of local conditions, so that the facts in hand are sufficient to warrant the general suggestions which will be offered. In estimating the value of a dietary one must know, in the first place, how much energy a person could profitably expend in his daily activities and what amount and variety of food is necessary to supply this. It has been calculated that a man engaged in active muscular work expends energy equal to about 150,000 metre-kilograms or 4,000 calories, a calorie representing the amount of heat required to raise one gram one degree Centigrade.[1] While it has not been possible, so far as I know, to determine the precise amount of energy expended by a student engaged in severe mental labor, yet one is warranted in assuming that it is not far below that indicated for a man employed in muscular pursuits,[2] and it is not incredible that it should be greater.

[1] Stevenson & Murphy, *Treatise on Hygiene*, Vol. I, p. 401.
[2] See, for instance, Sargent, North American Review, May, 1897.

To supply the energy required for all the needs of the organism during a day's activities, authorities agree substantially upon the quantity of the various food materials necessary, although the standards calculated for Germany and America are somewhat different, the American being considerably higher, probably due to the fact that our people are more active than the Germans, and are constantly expending more energy, possibly a good part of it going to waste. Atwater[1] gives the American and European dietary standard as follows:

[1] Op. cit., p. 18.

American and European dietaries and dietary standards.

[Quantities per man per day.]

DIETARIES.	NUTRIENTS.			Fuel values.	Nutritive ratio.*
	Protein.	Fats.	Carbohydrates.		
American (Massachusetts and Connecticut.)	*Lbs.*	*Lbs.*	*Lbs.*	*Cal.*	*1:*
Family of carpenter in Middletown, Conn.	.25	.28	.76	3,055	5.5
Family of glass-blowers in East Cambridge, Mass.	0.23	0.29	1.06	3,590	8.2
Boarding house, Lowell, Mass.; boarders, operatives in cotton mills	.29	.44	1.21	4,650	7.6
Boarding house, Middleton, Conn., well-paid machinists, etc., at moderate work — Food purchased	.28	.41	.94	4,010	6.8
Boarding house, Middleton, Conn., well-paid machinists, etc., at moderate work — Food eaten	.23	.34	.84	3,490	7.3
Blacksmiths, Lowell, at hard work	.44	.67	1.75	6,905	7.4
Brickmakers, Massachusetts; 237 persons at very severe work	.40	.81	2.54	8,850	11
Mechanics, etc., in Massachusetts and Connecticut; average of 4 dietaries of mechanics at severe work	.48	.65	1.65	6,705	6.6
Average of 20 dietaries of wage-workers in Massachusetts and Connecticut	.34	.50	1.38	5,275	7.5
Average of dietaries of professional men and college students in Middletown, Conn. — Food purchased	.30	.36	1.12	4,140	6.6
Average of dietaries of professional men and college students in Middletown, Conn. — Food eaten	.27	.34	1.08	3,925	6.6
European (English, German, Danish, and Swedish).					
Well-fed tailors, England, Playfair	.29	.09	1.16	3,055	4.7
Hard-worked weavers, England, Playfair	.34	.09	1.37	3,570	4.8
Blacksmiths at active labor, England, Playfair	.39	.16	1.47	4,115	4.7
Mechanic, Munich, 60 years old, in comfortable circumstances, light work, Forster	.26	.15	.76	2,525	4.3
Well-paid mechanics, Munich, Voigt	.34	.12	1.06	3,085	4
Carpenters, coopers, locksmiths, Bavaria; average of 11 dietaries, Voit	.27	.08	1.28	3,150	5.3
Miners at severe work, Prussia, Steinheil	.30	.25	1.40	4,195	6.7
Brickmakers (Italians), Munich, diet mainly maize meal and cheese, severe work, Ranke	.37	.26	1.49	4,540	5.6
German army ration, peace footing	.25	09	1.06	2,800	5
German army ordinary ration, war footing	.30	.13	1.08	3,095	4.6
German army extraordinary ration, in war	.42	.10	1.49	3,985	4.1
University professor, Munich; very little exercise, Ranke	.22	.22	.53	2,325	4.7
Lawyer, Munich, Forster	.18	.28	.49	2,400	6.3
Physician, Munich, Forster	.28	.20	.80	2,830	4.4
Physician, Copenhagen, Jurgensen	.30	.31	.53	2,835	4.1
Average of 7 dietaries of professional men and students, Germany, Denmark, and Sweden	.25	.22	.63	2,670	4.7
Dietary Standards.					
Adult in full health, Playfair	.26	.11	1.17	3,140	5.5
Active laborers, Playfair	.34	.16	1.25	3,630	4.7
Man at moderate work, Moleschott	.29	.09	1.21	3,160	4.9
Man at moderate work, Voit	.26	.12	1.10	3,055	5.3
Man at hard work, Voit	.32	.22	.99	3,370	4.7
Man with little physical exercise, Atwater	.20	.20	.66	2,450	5.5
Man with light muscular work, Atwater	.22	.22	.77	2,800	5.7
Man with moderate muscular work, Atwater	.28	.28	.99	3,520	5.8
Man with active muscular work, Atwater	.33	.33	1.10	4,060	5.6
Man with hard muscular work, Atwater	.39	.55	1.43	5,700	6.9

*The nutritive ratio is the ratio of the protein to the sum of all the other nutritive ingredients. The fuel value of the fat is two and a quarter times that of the protein and carbohydrates. In calculating the nutritive ratio the quantity of fats is multiplied by two and one-fourth. This product is added to the weight of the carbohydrates. The sum divided by the weight of the protein gives the nutritive ratio. Materials with

It is probable that these standards should be somewhat modified for persons engaged in intellectual pursuits, greater emphasis being laid upon the albuminoids and fats, and less upon the carbohydrates; or, what is perhaps a juster way to put it, the proportion of carbohydrates should be somewhat less in the dietary of a student than that appearing in any of the tables given. This inference is based upon a point discussed in preceding paragraphs, wherein it was said that the nutrition of nerve cells is believed to demand albuminoids and fats in largest ratio.

Taking now any one of the individual dietaries already given, say No. 1526, it will be possible to estimate with a fair degree of accuracy its worth judged by the standards here presented. Of course, considering that the exact amount of food eaten has not been indicated makes it impossible to determine the value only in a general or inferential manner. Assuming, however, that the quantity of each article consumed would be approximately the same for students and other adults we may gain some impression of the value of our dietary by comparing it with others when the articles are substantially the same, and where the amounts of each eaten have been accurately obtained and the nutritive value calculated. Such a study has been made in Boston under the direction of Atkinson,[1] and his results are indicated below:

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large amounts of fats or carbohydrates and little protein, like fat meats or potatoes, have a "wide" nutritive ratio. Those with a large amonnt of protein as compared with the carbohydrates and fats, like lean meat, codfish, and beans, have a "narrow" nutritive ratio. In other words, the materials rich in tissue forming substances have a narrow, and those with a large preponderance of fuel materials have a wide, nutritive ratio. This is an important matter in the adjusting of food to the demands of the body.

A well-balanced diet is one which has the right ratio of protein to the fats and carbohydrates. A relative excess of the tissue formers makes the ratio narrow, while an excess of the fuel ingredients makes an overwide ratio in the diet. Either of these errors is disadvantageous. Our food materials and our diet are apt to have too wide a nutritive ratio. In other words, we consume on the whole relatively too little protein and too much of the carbohydrates and fats.

[1] Op. cit., p. 150.

Sunday, February 22, 1890.

BREAKFAST.

	Man.	Woman.
	Ounces.	*Ounces.*
Milk	4	6
Flour griddle cakes	2½	4
Syrup	¼	½
Butter	⅛	¼
Cheese	¼	¼
Cream	3	½
Coffee	10	8
Sugar	½	Taste.
Oatmeal	11½	5
Water	4	0
	36⅛	24½

DINNER.

Cold corned beef	3	1½
Fat beef	½	0
Vegetables, parsnip, beet, turnip	5½+	5
Baked potatoes	8½ + 1½ oz. waste	9½ + 2½ oz. waste
Bread	2	0
Butter	1	1½
Fruit	3½ + ½ oz. waste	4 + ½ oz. waste
Nuts	1	¼
Raisins	0	¼
Water	18	12
	79⅛	58½

SUPPER.

Pear sauce	5 + 1 oz. sugar.	5 + 1 oz. sugar.
Bread	1¼	1¾
Cookie	¾ + ⅛ oz. sugar.	0
Butter	¼	¼
Crackers at bedtime	1	0
Water	0	12
Milk	6	0
	99⅜	71½
Less waste	5	5
	94⅜	66½

Calculation of the above:

MAN.

	Grms. albumen.	Fats.	Sugar.	Starch.	Grms. Total.
Milk	4.5	3.9	4.5	...	112
Cream	2.5	10.1	2.5	...	84
Butter	0.4	32.9	...	...	38
Cheese	2.1	2.2	...	...	7
Bread	6.4	0.5	...	41.4	91
Beef	28.6	6.3	...	...	84
Sugar	39	...	54	...	56
Potato	2	...	...	41.2	196
Vegetables	...	...	15.4	...	154
Fat in beef	...	14	...	...	14
Griddle cakes	10.5	...	...	35.0	70
Oatmeal	11.2	5.6	...	50.8	322 (80 dry)
Cookies	...	...	...	...	18
Nuts	4.5	15	...	9.7	28
Fruit	1.4	1.5	17	...	196
Crackers	2.0	0.1	...	15.8	28
Calories 2,384	80.00	92.1	297.3		1,498

WOMAN.

	Grms. Albumen.	Fats.	Sugar.	Starch.	Grms. Total.
Milk	13.4	11.8	13.4	...	336
Cream	0.4	1.7	0.4	...	14
Butter	0.6	48.4	...	...	56
Cheese	2.1	2.2	...	...	7
Bread	3.4	0.3	...	27.7	49
Beef	14.3	3.2	...	...	42
Sugar	...	...	33.8	...	35
Potato	3.9	...	...	41.2	196
Vegetables	1.8	...	14	...	140
Fat beef	...	...	...	...	0
Griddle cakes	16.8	...	...	56.0	112
Oatmeal	4.9	2.5	...	22.2	140 (35 dry)
Nuts	1.1	3.7	...	...	7
Fruit	...	...	18.3	...	210
Calories 1,859	62.7	73.8	227.0		1,344

Since the dietary standard given by Atwater calls for at least 125 grams of albumen, 125 grams of fat, and 450 grams of carbohydrates[1] it can be seen that Atkinson's man and woman did not consume enough of nutritious food. While these dietaries are deficient in all the food elements, the deficiency would be especially marked in respect of protein and fats if the guests were students. It is probable that the same thing can be said of dietary No. 1526. If the person living on this bill of

[1] Loc. cit.

fare should consume enough of the articles mentioned to supply the requisite amount of albuminous nutrients he would probably overload the organism with carbohydrates and waste matters; although this can be said not as founded upon direct and conclusive, but only upon indirect and inferential, evidence. It is suggestive to note in this connection that many authorities[1] have advanced the opinion that American dietaries as a rule accord too prominent a place to carbonaceous foods, and if this be true of our people at large, it must be especially true of the food of students. The predominance in the dietary lists of our students of such carbonaceous foods (and they are regarded as carbonaceous since the ratio of carbohydrates to protein is greater than that required for perfect nutrition) as white bread, potatoes, griddle cakes, cabbage, beets, and the like, indicates that they are too highly esteemed, relatively speaking, in our own locality, as they are elsewhere.

Kellogg maintains that the proportion of albumen to carbohydrates in a model bill of fare should be as 1 to 7, while Atwater demands that the ration be much richer in protein, the desired proportion being, in his opinion, about as 1 to 3 or 4. Other estimates lie somewhere between these extremes,[2] the weight of testimony, however, seeming to declare that Atwater's formula would give too "narrow" a ration, and that the albuminoids should not constitute more than 1-6 or 1-7 of the quantity of the other foods. Now, the composition of the ordinary food materials shows that few of them contain an excessive amount of protein, while the bulk of them are deficient in this respect, as will appear from the following table:

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[1]For instance, Jordan, op. cit., p. 57; Atwater, op. cit., p. 18.

[2]For a good discussion of the question, see Stevenson & Murphy, *loc. cit.*

Proportion of nitrogenous to carbonaceous elements in various foods.

	Album. or Nitrog.	Carbonaceous.		Album. or Nitrog.	Carbonaceous.
Lean beef	1	.5	Indian meal	1	7.7
Eggs	1	1.9	Rye meal	1	9.8
Peas	1	2.7	Potatoes	1	10.7
Beans	1	2 7	Carrots, and other vegetables (averaging)	1	11.0
Lentils	1	2.4	Barley meal	1	12.7
Milk	1	3.6	Rice	1	13.0
Fat beef	1	5.0	Common fruits (averaging)	1	80.0
Oatmeal	1	6.1			
Whole wheat meal or bread	1	7.0			

The quantities of some of the familiar foods which must be consumed daily in order that the required amount of protein may be obtained are shown below. The table gives warrant for the assertion that one whose dietary consists almost wholly of fruits, vegetables, white bread, tea and coffee can hope to gain but little more than enough nutrition to keep body and soul together.

Amounts of various foods necessary to furnish the proper daily amount of albuminous elements.

	Ounces.		Pounds.
Lean meat	15.6	Apples	99½
Eggs	21.2	Peaches	50.0
Peas	11.2	Plums	99½
Oatmeal	23.6	Cherries	22.0
Baker's bread	36.7	Carrots	15.0
Wheat flour (fine)	27.5	Turnips	16.0
Graham flour	25 5	Cabbage	22.0
Indian meal	26.8	Parsnips	18.0
Rye meal	37.1		*Pints.*
	Pounds.	Milk	4.5
Rice	3.0	Beer	185.0
Potatoes	8.8	Tea—Over 2½ lbs. dried leaves or 192 pints of strong infusion.	
Grapes	24⅞	Coffee—About 3 lbs. of dried berries.	

The too great proportion of carbohydrates and waste materials in some of our students' bills of fare could be balanced in a pleasing and economical manner by using more largely the pulse foods, as beans, peas and lentils; nut products, as nuttose, malted nuts, and protose; and substituting, at least in part, whole wheat bread made from such flour as the Purina Health Flour for the variety found so exclusively upon the tables in our community. And it should be pointed out especially that whole wheat bread and graham bread are not the same article, either in respect of nutritive value or readiness and ease of digestion. The graham bread with which we are all familiar contains the outer husk of the wheat kernel, which cannot be assimilated, and which seems to accomplish little else than to irritate the digestive tract. Whole wheat flour, on the other hand, possesses the great advantage of having the fibrous covering removed while preserving all of the albuminous part of the kernel. In the ordinary white bread, however, a large fraction of the albuminous part of the wheat is removed in milling. Church discusses this point so satisfactorily that I may quote his words:[1]

"There are two parts of the wheat grain which, in various milling processes, are often removed. One of these is the germ, the other is the outermost coat of the grain. The germ is removed in roller-milling, because its presence tends to discolor the flour, and gives it a marked tendency, especially when kept under unfavorable conditions, to acquire a rancid taste and odor. That the exclusion of the germ is to be regretted on dietetic grounds is evident when its singular richness in oil, in nitrogenous matters, and in phosphoric acid, is considered. The following analysis was made on a pure sample of flattened germs from a roller-mill:—

	In 100 parts.
Water	12.5
Albuminoids, diastase, etc	35.7
Starch, with some dextrin and maltose	31.2
Fat or oil	13.1
Cellulose	1.8
Mineral matter	5.7

More than half this mineral matter was phosphoric acid; indeed, it amounted to no less than 60.6 per cent. of the total ash, so that the original embryos contained nearly 3½ parts per hundred of this valua-

[1] Op. cit., p. 70.

ble constituent of bone. The nitrogenous matters amounted to thrice the proportion present in the whole wheat grain; the oil or fat was more than six times as much. It should be added that the albuminoid matter included little or no tenacious gluten, but a considerable quantity of the diastatic ferment.

"But if, on some grounds, the exclusion of the germ from our mill-products is a procedure of doubtful utility, there can be no question that the removal of the fibrous outer envelope of the grain is of considerable advantage. The following figures were obtained in the analysis of a carefully prepared sample:—

	In 100 parts.
Water	15.2
Albuminoids (from total nitrogen)	10.4
Oil	2.5
Ash or mineral matter	2.6

To these analytical results it may be added that this ash contained no more than 15.3 per cent. of phosphoric acid. All these results, and the high proportion of fiber present, contrast very strongly with those previously given in the analysis of the germ."

If now one desired to work out his daily dietary so as to obtain the right proportions of albuminous and carbonaceous elements with something like mathematical accuracy, which process, if it demanded his constant attention and made him over-conscious of his food, would certainly be an unwise proceeding;—but if he wished to do it, he might proceed according to the following scheme (Kellogg):

Combine 8	ounces lean beef	with 4 pounds 8 ounces potatoes.
Combine 7½	ounces lean beef	with 1 pound 8 ounces rice.
Combine 1½	ounce lean beef	with 1 pound 8 ounces Indian meal.
Combine 12	eggs	with 1 pound 6 ounces rice.
Combine 9	eggs	with 5 pounds 2 ounces potatoes.
Combine 3	pints of milk	with 1 pound of rice.
Combine 2¼	pints of milk	with 4 pounds 4 ounces potatoes.
Combine 7½	ounces peas	with 1 pound 4 ounces rice.
Combine 6	ounces peas	with 5 pounds of potatoes.
Combine 5	ounces oatmeal	with 5 ounces rice.
Combine 4	ounces oatmeal	with 1 pound 11 ounces potatoes.
Combine 4	ounces oatmeal	with 5 ounces rye meal.
Combine 15	ounces oatmeal	with 10 ounces Indian meal.

A word should be said of the heat-producing properties of foods, since the extremes of climate in these regions make this a very important matter. Yet it is almost entirely disregarded

by the makers of bills of fare in our midst. Fats have as prominent a place on our tables in mid-summer as in mid-winter; there seems to be a sort of stereotyped form that is used all the year round. But the organism loaded with calorifacient foods in our hottest weather is obviously at a great disadvantage; just as is one deprived of a liberal allowance of them in January or February. Landlords should know something of the calorific qualities of different articles, such information, for instance, as that presented in the accompanying chart, and they should take into account the standing of the thermometer when constructing a bill of fare.

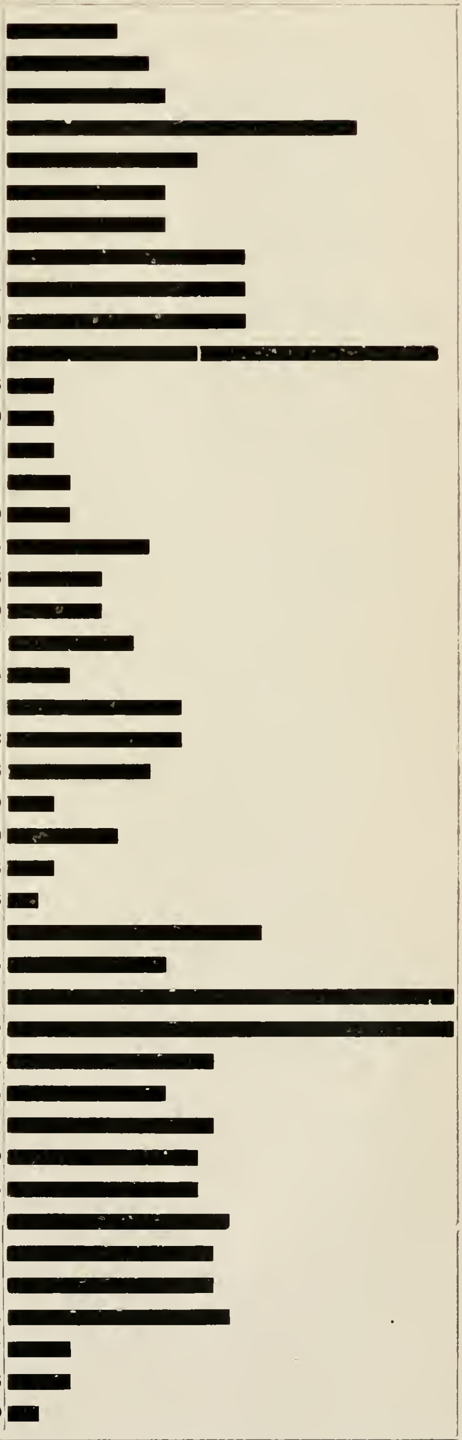
So much has been said regarding the evil of making carbohydrates too prominent in one's dietary that a word is demanded respecting the tendency in some cases of consuming more albumen in the daily ration than the organism can utilize. This is liable to be the case where one eats heartily of lean meat three times a day, while at the same time not reducing the amount of other substances rich in protein. Suppose that one eats five ounces of lean beef at each of three meals, he will obtain 4.45 ounces of protein, the maximum amount for a man engaged in active labor, mental or physical. Then if he add bread, peas, milk, puddings, and nuts, he will convey into his system a considerable quantity of albumen that will have to be eliminated unused; and it seems reasonable to suppose that the working capacity of the organism will be in so far reduced. Overeating in this way must be regarded as lessening the efficiency of the organism in somewhat as serious a sense perhaps as undereating.

An examination of dietary No. 1101 shows that meat was eaten three times every day for a week, and to this were added each day a cereal rich in albumen, besides bread, milk, corn, eggs, and other articles. Now, if this guest ate heartily of meat at each meal, it is practically certain that he consumed more protein than he could utilize, and it must consequently have been a hindrance rather than a help to him. Everyone is doubtless familiar with the opinions of physicians to the effect that sed-

Chart showing calories in the nutrients in one pound of each food material.

(Atwater.)

Beef, round, rather lean	807
Beef, neck	1,108
Beef, sirloin, rather fat	1,173
Beef, flank, very fat.........	2,750
Beef, side, well fattened....	1,463
Mutton, leg..................	1,142
Mutton, shoulder	1,281
Mutton, loin (chops)........	1,755
Mutton, sides, well fattened	1,906
Smoked ham	1,960
Pork, very fat...............	3,152
Flounder	286
Cod	310
Haddock	331
Bluefish	404
Mackerel, rather lean.......	430
Mackerel, very fat	1,026
Mackerel, average	696
Shad.........................	750
Salmon	967
Salt cod	416
Salt mackerel	1,364
Smoked herring.............	1,343
Canned salmon..............	1,036
Oysters	229
Hen's eggs..................	760
Cow's milk	308
Cow's milk, skimmed.......	176
Cheese, whole milk	2,044
Cheese, skimmed milk......	1,166
Butter	3,691
Oleomargarine	3,679
Wheat flour	1,655
Wheat bread	1,278
Rye flour	1,614
Beans........................	1,519
Peas	1,476
Oatmeal.....................	1,830
Corn (maize) meal..........	1,616
Rice	1,627
Sugar........................	1,798
Potatoes.....	427
Sweet potatoes.............	416
Turnips......................	139



entary people especially should eat sparingly of meat if they are generous in their daily allowance of other protein-bearing foods,[1] since elimination is a relatively serious matter for those who are not active muscularly much of the time. Many believe, and it seems with a show of reason, that sedentary people should get their albuminous foods in some other substances, for the most part, than meat, since all flesh contains worn out products that have not been eliminated in the life of the animal, and that are not only valueless for the purposes of nutrition, but are moreover a sort of drug in the system. A student eating a large amount of beefsteak, for instance, from which the blood has not been thoroughly drawn, and not exercising a great deal, cannot but be handicapped in mind and body, since his organism must become clogged up with the toxic products of his own activities and of those of the animal which he imports into his system.

§3. *Specimen Dietaries Fulfilling the Requirements of Adequate Nutrition.*—In view of what has been presented in preceding sections it may be instructive now to show in actual bills of fare how the principles which have been advanced can be embodied in practice. Atwater, Atkinson, Kellogg, and others have constructed dietaries indicating the required daily amount of each article of food which in the total will give the right quantity of the several nutrient elements. The food materials used in these dietaries are substantially such as constitute the body of the bills of fare of our students; and while some of these could with great advantage be banished from our tables and other articles substituted in their stead (for instance, nut foods taking the place of pork in every form, and much of the other flesh, cream being used more largely in the place of butter, the nitrogenous cereals discussed in §4 being added to the lists, etc.), yet it will be well to see what can be done with those things, valueless as some of them are, that tradition keeps

[1] See The North American Review, Vol. 164, p. 664, for expert opinion upon this subject.

in the diet lists of students as of other people. In the case of Atwater's tables the cost is given, and this will be referred to later.

Daily dietaries—Food materials furnishing approximately the 0.28 pound protein and 3,500 calories of energy of the standard for daily dietary of a man at moderate muscular work.

Food materials.	Amount.	Cost.	Nutrients.				Fuel value.
			Total.	Protein.	Fats.	Carbohydrates.	
	Ounces.	*Cents.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Calories.*
Beef, round steak	13	11.40	.26	.14	.12	....	695
Butter	3	5.65	.16	....	.16	....	680
Potatoes	6	1.25	.17	.02	....	.15	320
Bread	22	5.50	.89	.12	.02	.75	1,760
	44	23.80	1.48	.28	.30	.90	3,455
Pork, salt	4	3	.21	....	.21	....	880
Butter	2	3.75	.11	....	.11	....	450
Beans	16	5	.84	.23	.02	.59	1,615
Bread	8	2	.33	.04	.01	.28	640
	30	13.75	1.49	.27	.35	.87	3,585
Beef, sirloin steak	12	15	.25	.12	.13	....	725
Butter	3	5.65	.16	....	.16	....	680
Milk, 1¾ pints	28	6.15	.22	.06	.08	.08	570
Potatoes	12	.95	.12	.01	....	.11	240
Flour	12	1.85	.65	.08	.01	.56	1,235
	67	29.60	1.40	.27	.38	.75	3,450
Beef, neck	10	4.40	.19	.10	.09	....	550
Butter	1	1.90	.05	....	.05	....	225
Milk, 1 pint	16	3.50	.13	.04	.04	.05	325
Potatoes	16	1.25	.17	.02	....	.15	320
Oatmeal	4	1.25	.23	.04	.02	.17	460
Bread	16	4	.67	.09	.02	.56	1,280
Sugar	3	.95	.19	....	....	.19	345
	66	17.25	1.63	.29	.22	1.12	3,505
Beef, shoulder	8	6	.16	.09	.07	....	450
Salmon, canned	4	3.75	.10	.05	.05	....	245
Butter	2½	4.70	.13	....	.13	....	565
Milk, 1½ pints	24	5.25	.18	.05	.06	.07	485
Potatoes	8	.65	.09	.01	....	.08	160
Oatmeal	2	.65	.11	.02	.01	.08	230
Flour	10	1.55	.55	.07	.01	.47	1,030
Sugar	3	.95	.19	....	....	.19	345
	61½	23.50	1.51	.29	.33	.89	3,510
Beef, sirloin steak	8	10	.17	.08	.09	....	485
Mutton chops	5	6.25	.14	.04	.10	....	465
Butter	2	3.75	.11	....	.11	....	450
Milk, 1½ pints	24	5.25	.18	.05	.06	.07	485
Potatoes	8	.65	.09	.01	....	.08	160
Oatmeal	3	.95	.17	.03	.01	.13	345
Bread	12	3	.50	.07	.01	.42	965
Sugar	2	.65	.12	....	....	.12	230
	64	50.50	1.48	.28	.38	.82	3,585

Daily dietaries—Food materials furnishing approximately the 0.28 pound of protein and 3,500 calories of energy, etc.—Continued.

Food materials.	Amount.	Cost.	Nutrients.				Fuel value.
			Total.	Protein.	Fats.	Carbohydrates.	
	Ounces.	*Cents.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Calories.*
Beef, round steak.	8	7	.16	.09	.07	....	425
Cod, dried.........	2	.90	.03	.03	....	....	40
1 egg..............	1½	2.00	.02	.01	.01	....	70
Butter..............	3	5.65	.16	....	.16	....	680
Milk, 1¼ pints.....	20	4.40	.15	.04	.05	.06	405
Potatoos...........	8	.65	.09	.01	....	.08	160
Oatmeal	2	.65	.12	.02	.01	.09	230
Flour	10	1.55	.55	.07	.01	.47	1,030
Sugar	4	1.25	.25	....	....	.25	460
	58½	24.05	1.53	.27	.31	.95	3,500
Beef, shoulder.....	9	6.75	.18	.10	.08	....	515
Ham...............	6	6	.19	.06	.13	....	655
One egg............	1½	2	.02	.01	.01	....	70
Butter..............	1½	2.80	.08	....	.08	....	340
Milk, ½ pint	8	1.85	.06	.02	.02	.02	165
Potatoes (white)..	8	.75	.09	.01	....	.08	160
Sweet potatoes....	8	1	.12	.01	....	.11	210
Corn meal	8	1.25	.42	.05	.02	.35	825
Bread..............	4	1	.16	.02	....	.14	320
Sugar..............	2	.65	.12	....	....	.12	230
	56	23.85	1.44	.28	.34	.82	3,490
Ham	8	8	.24	.07	.17	....	870
Cod, dried.........	4	1.75	.02	.02	....	....	50
Three eggs.........	4½	6	.07	.04	.03	....	200
Butter..............	1½	2.80	.08	....	.08	....	340
Cheese	1	1	.04	.02	.02	....	130
Milk, 1 pint........	16	3.50	.13	.04	.04	.05	325
Potatoes (white)..	6	.50	.07	.01	....	.06	120
Sweet potatoes....	8	1	.12	.01	....	.11	210
Corn meal	8	2.50	.42	.05	.02	.35	825
Bread	4	1	.16	02	....	.14	320
Sugar..............	2	.65	.12	....	....	.12	230
	63	28.70	1.47	.28	.36	.83	3,620

Kellogg[1] has determined the nutritive values of different portions of the common articles of diet, as well as some that are not so well known, and his results are of much practical interest. By means of the tables here given one could make combinations of foods with something like precision and definiteness.

[1] *Balanced Bills of Fare*—Good Health Pub. Co., Battle Creek, Mich.

Nutritive value of foods.

Food.	Weight Oz.	Measure.	Per Cent. of			Calories in 1 oz.
			Proteids.	Fats.	Carbohydrates.	
Bananas	2.	1 peeled	1.4	1.4	29.8	39
Oranges	2.	1 peeled	1.31	....	11.	14
Lemons	2.5	1 peeled	1.	.9	8.3	14
Berries, stewed	9.8	.5 pint	1.4	....	12.4	16
Dates	2.	7	.9	....	58.	67
Prunes, stewed	9.2	.5 pint	.5	....	14.7	17
Raisins, stewed	9.2	.5 pint	1.8	1.9	23.6	34
Apple sauce	9.5	.5 pint	.18	.24	9.4	12
Peaches, canned	9.2	.5 pint	.7	....	12.5	15
Fruit-juice	8.8	.5 pint	.7	.74	9.2	13
Sauce for grains	8.5	.5 pint	.7	.7	9.8	13
Apples, fresh	13.	2 large or 4 small	.4	....	12.	14
Grapes, fresh	5.	1 av. bunch	.6	....	16.3	19
Peaches, fresh	3.	1 peeled and pitted	.7	....	12.5	15
Apricot, canned	9.5	.5 pint	.5	....	11.	13
Grape pulp	....	....	2.	.2	21.	32
Blackberry, canned	9.2	.5 pint	.5	....	5.5	7
Cherry, canned	9.2	.5 pint	.7	....	12.	15
Pear, canned	9.2	.5 pint	.4	....	11.5	14
Strawberry, canned	9.2	.5 pint	1.1	.5	6.8	9
Whortleberry, canned	9.2	.5 pint	.8	....	5.9	8
Melon	....	....	1.	.3	2.2	5
Plum	....	....	.4	....	8.2	10
Fig	....	....	4.	....	49.8	62
Tomato	8.	1 medium	1.6	.3	2.5	12
Apple, baked	5.5	1 large	.18	.24	9.4	5
Rice, steamed	5.75	.5 pint	3.	.16	31.4	40
Oatmeal	....	.5 pint	6.4	3.9	29.7	53
Crystal wheat	7.	.5 pint	5.7	3.	29.5	49
Gluten mush	8.25	.5 pint	12.	.6	22.	44
Graham mush	7.	.5 pint	5.8	.9	35.8	52
Wheatose	7.	.5 pint	5.7	.8	29.5	44
Rice with nuttose	6.	.5 pint	4.2	1.3	32.1	46
Macaroni	6.5	.5 pint	10.	2.	75.	104
Granola	4.25	.5 pint	15.	3.	75.	114
Granose	2.75	4	15.4	2.3	79.1	117
Zwieback	2.2	2 pieces	13.6	2.	70.	104
Graham crackers	3.	6	9.8	13.6	70.	128
W. W. wafers	2.5	6	9.8	13.6	70.	128
Beaten biscuit	2.25	6	11.7	1.2	80.	110
Sticks	2.	12	11.7	1.2	80.	110
Rolls	4.	6	11.7	1.2	80.	110
Passover bread	3.75	12	11.7	1.2	80.	110
Graham bread	1.	1 piece	9.5	1.4	53.3	80
W. W. bread	1.	1 piece	9.8	1.4	50.7	75
W. bread	1.	1 piece	8.8	1.7	56.3	81
Nut-gravy toast	6.	1 piece	6.8	1.	35.	52
Prune toast	6.	1 piece	6.8	1.	35.	52
Berry toast	6.	1 piece	6.8	1.	35.	52
Cream toast	6.	1 piece	6.8	1.	35.	52
Nuttose roast	6.	.5 pint	4.3	1.9	12.5	25
Nuttose and tomato	8.75	.5 pint	4.3	1.9	12.5	25
Potato, mashed	7.75	.5 pint	3.2	.15	27.5	36
Vegetables, fresh	8.	.5 pint	1.6	.3	4.	8
Tomato, stewed	8.	.5 pint	.8	.15	1.25	3
Potato, baked	4.	1 medium	3.2	.15	27.5	36
Nut gravy	9.	.5 pint	....	....	....	....
Soup	8.5	.5 pint	.8	.2	1.	3
Sugar	7.	.5 pint	....	....	97.8	111
Beans, boiled	8.75	.5 pint	....	....	....	....

Nutritive value of foods—continued.

Food.	Weight Oz.	Measure.	Per Cent. of Proteids.	Per Cent. of Fats.	Per Cent. of Carbohydrates.	Calories in 1 oz.
Cream	8.5	.5 pint	2.7	26.7	2.8	75
Milk	8.5	.5 pint	3.6	4.	4.7	21
Egg	1.5	1	14.	10.5	....	47
Sterilized butter	....	....	1.	85.	....	218
Kumyss	8.5	.5 pint	3.7	3.6	4.7	20
Cottage cheese	....	....	3.6	3.7	6.	20
Malted nuts	....	....	23.	20.4	49.3	140
Almond cream	....	....	2.7	26.7	2.8	75
Nut butter	8.75	.5 pint	16.4	26.4	9.5	101
Bromose	1.	2 cakes	19.6	24.	39.4	135
Maltol	9.	.5 pint	....	20.	75.	136
Nuttose	3.	....	30.	30.	18.	139
Nuttolene	3.	....	30.	30.	18.	139
Nut meal	3.75	.5 pint	28.3	46.2	1.8	161
Stewed nuttolene	9.	.5 pint	....	....	....	....
Beefsteak	....	....	19.3	3.6	.0	37

Constructing bills of fare from these tables we could make combinations like the following, which, according to Kellogg, are each equal to one-half of a ration, while Atwater and others would estimate them at one-third of a ration. Kellogg would advise only two meals a day, each affording the amount of food indicated in the combinations given; while Atwater would counsel three meals a day.

Combination bills of fare.

Foods.	Weight Oz.	Measure.	Calories or food units.	
Beefsteak	7	½ pound	Proteids	345
Oatmeal	2½	1-6 pint	Fats	175
Bread, white	6	6 slices	Carbohydr.	925
Potato	6	⅓ pint		
Beans	1½			
Bananas	7	3		
	30		Total	1,445
Eggs	3	2	Proteids	197
Bread, white	5	5 slices	Fats	526
Oatmeal	8	½ pint	Carbohydr.	590
Butter	2			
	18		Total	1,313
Bread, white	10	10 slices	Proteids	199
Milk	8	½ pint	Fats	458
Cream	5	⅓ pint	Carbohydr.	633
	23		Total	1,290
Kumyss	13	¾ pint	Proteids	296
Malted nuts	7		Fats	434
			Carbohydr.	461
	20		Total	1,241
Passover bread	4	13 pieces	Proteids	200
Macaroni	4	¼ pint	Fats	162
Tomato	9	1	Carbohydr.	818
Bromose	2			
	19		Total	1,180
Beefsteak	8	½ pound	Proteids	364
Potato	10	⅝ pint	Fats	113
Bread, white	8	8 slices	Carbohydr.	823
	26		Total	1,300
String beans	8	½ pint	Proteids	205
Tomatoes	16	2 large	Fats	409
Soup	12	¾ pint	Carbohydr.	619
Nuttose roast	7	⅓ pint		
Graham bread	7	7 slices		
Sterilized butter	1⅓			
	51⅓		Total	1,323

CHAPTER IV.

RELATIVE VALUE OF FOODS IN THE PRODUCTION OF NERVOUS ENERGY (cont.).

§1. *Condiments as Force Producers.*—A word should be said regarding those articles often designated as food adjuncts or food accessories, or more familiarly, condiments. These include the spices, peppers, pickles, vinegars, and all the things designed to whet the appetite, as we say. No one maintains that they possess any nutritive value, but many believe they are essential to the excitation of the digestive juices, and hence are of much worth in one's dietary. Authorities seem to agree that when food is unpalatable some of these artificial excitants may be of service; but this does not imply that the materials most nutritious and wholesome do not possess in themselves flavors which may be developed by proper cooking and which will be sufficiently stimulating to secure a generous flow of digestive juices. It deserves more than passing notice that young children cannot be induced to take food adulterated, so to speak, with these foreign substances; and it seems to be only when the digestive processes become deranged from abnormal and injurious practices that unnatural stimulants must be employed. Grant Allen[1] has pointed out that whiskey, pepper, and the like are usually found together in one's diet; organs thus overstimulated crave a continual increase in stimuli until it happens that one can enjoy no food in its natural flavors, and must add pepper, vinegar and whiskey to everything he eats in order that he may endure it at all.

On the tables in our own locality vinegar is the acid condiment most universally employed, alike in its pure state, and obscured in pickles, preserves, and similar "relishes." It is, of

[1] *Popular Science Monthly*, Vol. 26, p. 468.

course, generally known that vinegar is the result of decomposition of natural fruit juices which contain the various acids, as malic, citric, etc., needed by the system to promote right digestive and eliminative processes. Vinegar, that is to say, is not found in ripened fruits before decomposition takes place. Now it is doubtless a principle of universal application in nutrition that foods are best appropriated when they are gained in their native forms, so to speak, as found in ripened fruits and grains or in animal flesh. It is to be regretted that apples and other fruits do not occupy a more prominent place in our dietary lists, when there would be less need of "pickles." The more general use of unfermented fruit juices served as sauces, for instance, is also greatly to be desired in our midst.

§2. *The Influence of Tea, Coffee and Cocoa Upon the Production and Expenditure of Force in the Organism.*—From the point of view which is being taken in this bulletin in the discussion of nutrition, the most important food accessories are those which have a marked effect upon the central nervous system, as tea, coffee, cocoa, and the various forms of alcoholic "drinks,"—wine, beer, whiskey, and the like. It has long been held that a cup of tea or of coffee cheers but does not inebriate; and it has come to be generally felt that tea and coffee are necessary adjuncts to one's diet. Nearly every student enjoys his cup or cups of tea or coffee at every meal and many apparently believe they derive real nutrition from these beverages. The analyses[1] of tea, coffee, and cocoa which follow show, though, that while they possess a modicum of nutrients, yet one gets such a small allowance of these in the quantity of tea or coffee which can be imbibed at any meal that their nutritive value is practically zero.

[1] Church.

Analyses of tea, coffee, and cocoa.

	In 100 parts.	In 1 pound.	
		Oz.	*Gr.*
Composition of black tea:			
Water	8.0	1	122
Albuminoids	17.5	2	350
Theine	3.2	0	234
Tannin	17.5	2	350
Chlorophyll and resin	4.5	0	315
Essential oil	0.4	0	28
Minor extractives	8.6	1	164
Cellulose, etc	34.0	5	193
Mineral matter	6.3	1	4
Composition of roasted coffee:			
Water	2.0	0	140
Albuminoids	12.5	2	0
Theine (Caffeine)	1.0	0	70
Fat or oil	12.5	2	0
Tannin	5.0	0	350
Minor extractives	14.4	2	133
Cellulose, etc	48.0	7	297
Mineral matter	4.6	0	322
Composition of cocoa:			
Water	5.0	0	350
Albuminoids	12.5	2	0
Fat	50.0	8	0
Theobromine	1.0	0	70
Cacao-red	3.0	0	210
Tannin	6.0	0	420
Gum, etc	7.0	1	32
Cellulose and insoluble matter	12.5	2	0
Mineral matter	3.0	0	210

People do not commonly prize tea and coffee, however, for their nutritive worth, but only for the stimulating effect which they exert upon the nervous system. Smith[1] has carefully studied their action upon the vital functions and it will be well to give the results of his experiments. And first regarding tea:

"*1. As to the Carbonic Acid Evolved in Respiration.*

"1. One hundred grains of the finest black tea gave a maximum increase of 0.87 grain and 1.72 grain per minute in 50 and 71 minutes on two persons.

"2. Fifty grains gave to four persons maxima of increase of 1.08, 1.38, 2.58, 1.6, 2.0, and 0.69 grains per minute, under different experiments.

"3. One hundred grains of the finest green tea, drank when cold, gave maxima of increase of 0.9, 2.58, and 0.64 grains per minute on three persons.

"4. Twenty-five grains of green tea, drank when cold, and after hav-

[1] Op. cit., pp. 347–350.

ing been infused several hours, and repeated every quarter of an hour, for five doses, gave an average increase of 1.2 and a maximum increase of 1.8 grain per minute. The total increase, as shown by ten observations, was no less than 193 grains; and at the close of the experiment the increase continued at the rate of 54 grains per hour.

"5. When 150 grains of black tea, infused in one pint of water, were taken, and the whole carbonic acid was collected for 65 minutes, it was shown that there had been an excess of 51.36 grains evolved, which was not more than one-fourth of the total increase when the tea had been divided into repeated doses.

"6. When we took 100 grains of black tea, and the whole carbonic acid was collected during 1 hour and 50 minutes, the total increase was 70.40 grains.

"*2. As to the Volume of Air Inspired.*

"There was an average increase in the quantity of air inspired in every experiment but one. Thus pursuing the order of the above mentioned experiments,

In No. 1, the quantity was increased by 71 and 68 cubic inches per minute.

In No. 2, the increase was 34, 39, 50, 72, 95, and 26 cubic inches per minute.

In No. 3, the average increase was 120 and 50 cubic inches.

In No. 4, the average increase was 66 cubic inches.

In No. 5, the maximum increase was 92 cubic inches.

In No. 6, the average increase was 47.5 cubic inches.

"*3. As to the Depth of Inspiration.*

"The rate of respiration either did not increase or was lessened; and as the volume of air inspired was increased, the depth of inspiration was greater so that the increased volume of air inspired at each inspiration varied from 3 to 10.6 cubic inches. With this increased depth, there was also a sense of greater freedom of respiration.

"*4. As to the Rate of Pulsation.*

"The rate of pulsation followed that of respiration, but in a less degree, and was either not increased or was slightly decreased.

"Hence it was proved beyond all doubt that tea is a most powerful respiratory excitant. As it causes an evolution of carbon greatly beyond that which it supplies, it follows that it must powerfully promote those vital changes in food which ultimately produce the carbonic acid to be evolved. Instead, therefore, of supplying nutritive matter, it causes the assimilation and transformation of other foods . . . .

"Hence, in reference to nutrition, we may say that tea increases waste, since it promotes the transformation of food without supplying nutriment, and increases the loss of heat without supplying fuel, and it is therefore especially adapted to the wants of those who usually eat too much, and after a full meal, when the process of assimilation should be quickened, but is less adapted to the poor and ill-fed, and during fasting."

His experiments with coffee show an influence similar in a way to that of tea. He says:[1]

"Of twenty-three experiments on myself and others there was from half an ounce of coffee an increase in the quantity of carbonic acid evolved of 0.98, 1.02, 0.9, 0.4, 1.16 and 2.54 grains per minute at different times, whilst the quantity of air inspired was increased 40, 34, 35, and 84 cubic inches per minute with the same experiments. Three-quarters of an ounce of coffee did not give a greater increase, but the actual increase was 0.68 and 1.68 grain of carbonic acid and 28 and 54 cubic inches of air per minute.

"The conditions, therefore, under which coffee may be taken are very different from those suited to tea. It is more fitted than tea for the poor and feeble. It is also more fitted for breakfast, inasmuch as the skin is then active and the heart's action feeble; whilst in good health and with sufficient food it is not needful after dinner, but if then drank should be taken soon after the meal. Hence in certain respects tea and coffee are antidotes of each other, and we know that they are now taken indiscriminately, although in a chief action they are interchangeable.

"Coffee is an excitant of the nervous system, but not in the same degree as tea. It produces sleeplessness in many persons when it is taken at night, probably by exciting the heart's action, and preventing that fall which is natural at night, and requisite to permit sound sleep. I do not think that there is the same degree of reaction after taking strong coffee as follows strong tea. It is needless to add, that none of these effects may be marked if the infusion be very weak, as is common among the poor, and in this respect it resembles very weak tea."

I am not familiar with the results of experiments relating to the influence of cocoa; but it is known that its active principle, theobromine, resembles the active principles of tea and coffee, theine and caffeine, and it is probable that its action in the system is somewhat like these.

[1] Op. cit., pp. 365–367.

It must be apparent, then, that these beverages containing alkaloids really operate in dissipating rather than in conserving energy. They are doubtless of assistance to an organism that needs to get rid of superfluous materials. One who does not require all the energy of his food for mental or physical labor may to advantage call tea and coffee to his aid to relieve his system of a burden. But this is a situation which does not commonly exist in student life. Students, as a body, are not likely to consume more food than is required for the best efficiency of mind and body even when the total amount of energy it yields is expanded in profitable production. And then the average college man or woman is illy prepared, from the financial point of view, to provide for the waste of food which the habitual use of tea and coffee entails. It is recognized, of course, that conditions may exist when tea, coffee, and similar things have a therapeutic value; but we are concerned here not with the needs of the organism in disease but only in full health and vigor.

The exhilaration which follows a cup of tea or coffee is significant for the psychologist as well as for the student in the practical affairs of daily life. This is possibly due to a paralyzing effect for the moment upon the inhibitory or controlling mechanisms in the central nervous system which report the true condition of the organism, and seek to prevent it from passing the safety line in its activities. To illustrate the theory by fatigue: The fatigue sense, as has been said, exerts an inhibiting influence upon activity; the rate and strength of movements show decrease; mind and body become relaxed, and under normal conditions the individual tends to fall asleep in order that there may be repair of waste. When this sense reports the status of the body in fatigue there is a feeling of depression, of lassitude; but if its restraining power can be overcome in any way there will apparently be a return of wonted vigor. But what the welfare of the system requires at this time is rest and food to restore dissipated energy, not incitement to still greater dissipation; and while in certain situations it may be

advisable to stimulate by weakening the controlling and warning functions of the body, yet to make this a systematic, daily practice is to render the organism in the end less efficient mentally and physically. It is not an over-statement to say that a student living a normal life with all his powers under control, which requires, speaking neurologically, that his nervous system should be in a state of thorough nutritive repair,—such a student will not be benefited but rather be injured by the stimulations derived from habitual indulgence in tea and coffee.

Before taking leave of this subject I must quote the testimony of Williams[1] regarding his personal experience with tea:

"I recommend tea drinkers who desire to practically investigate the subject for themselves to repeat the experiment that I have made. After establishing the habit of taking tea at a particular hour, suddenly relinquish it altogether. The result will be more or less unpleasant, in some cases seriously so. My symptoms were a dull headache and intellectual sluggishness during the remainder of the day—and if compelled to do any brain-work, such as lecturing or writing, I did it badly. This, as I have already said, is the diseased condition induced by the habit. These symptoms vary with the amount of the customary indulgence and the temperament of the individual. A rough, lumbering, insensible navvy may drink a quart or two of tea, or a few gallons of beer, or several quarterns of gin, with but small results of any kind. I know an omnibus driver who makes seven double journeys daily, and his 'reglars' are half a quartern of gin at each terminus—i. e., 1¾ pints daily, exclusive of extras. This would render most men helplessly drunk, but he is never drunk, and drives well and safely.

"Assuming, then, that the experimenter has taken sufficient daily tea to have a sensible effect, he will suffer on leaving it off. Let him persevere in the discontinuance, in spite of brain languor and dull headache. He will find that day by day the languor will diminish, and in the course of time (about a fortnight or three weeks in my case) he will be weaned. He will retain from morning to night the full, free, and steady use of all his faculties; he will get through his day's work without any fluctuation of working ability (provided, of course, no other stimulant is used). Instead of his best faculties being dependent on a drug for their awakening, he will be in the condition of true manhood,—i. e., able to do his best in any direc-

[1] *Chemistry of Cooking*, p. 257.

tion of effort, simply in reply to moral demand; able to do whatever is right and advantageous, because his reason shows that it is so. The sense of duty is to such a free man the only stimulus demanded for calling forth his uttermost energies."

To obviate the evils attendant upon the continual use of tea and coffee Count Rumford made a suggestion many decades ago which is being practically embodied today in the manufacture of a substitute therefor. He gave these directions for the preparation of the substitute:[1] Take eight parts by weight of meal and one part of butter. Melt the butter in a clean iron frying pan; and when thus melted, sprinkle the meal into it. Stir the whole briskly with a broad wooden spoon or spatula until the butter has disappeared and the meal is of a uniform brown color like roasted coffee, great care being taken to prevent burning on the bottom of the pan. A small portion of this composition was then to be placed in boiling water and an infusion obtained in the same way as in the case of tea or kindred beverages. This would answer one purpose, if none other, for which many people imbibe tea and coffee, that they may have a warm drink while partaking of solid food. Rumford's substitute has been much improved upon in our own day in the manufacture of cereal coffees which are in some instances at any rate alike palatable and nutritious. It would certainly be of advantage to a student in the economy of his energies and his purse if he should reduce the quantity of his tea and coffee, replacing it in whole, or at least in part, by Count Rumford's substitute, or some other modern version of the same. It perhaps should be said that one who has acquired great fondness for the stouter drinks will not at the beginning find the substitute quite so agreeable to the palate because not so stimulating; but I have been able to observe a trial made in a boarding house in our own city where in several cases the use of the substitute for a few days served to make it thoroughly acceptable, and even replaced the older beverages in the novices' favor.

[1] Williams, op. cit., p. 245.

§3. *The Influence of Alcohol in Wine, Beer, and Other Beverages in the Production and Expenditure of Force.*—We come now to discuss a group of articles demanding particular consideration,—those containing alcohol in combination with various other ingredients, as found in beer, wine, whiskey, and the like. It was not thought necessary nor perhaps desirable to try to find out in our questionnaire how extensively these are used by our own students; but it is well known, of course, that to some extent here, as elsewhere, alcoholic beverages are indulged in. The composition of beer and wine, the beverages most commonly drunk, reveals at the outset the fact that they cannot be regarded as foods in the proper sense. The following is the list of the chief compounds known to occur in beer:[1]

1. Alcohol, or spirits of wine, from 8 to 3 per cent.
2. Dextrin, about 4.5 per cent.
3. Albuminoids, about 0.5 per cent.
4. Sugar, about 0.5 per cent.
5. Acetic, Lactic, and Succinic Acids, about 0.3 per cent.
6. Glycerin, about .22 per cent.
7. Carbonic Acid Gas, about 0.22 per cent.
8. Mineral matter, about 0.3 per cent.

The following table shows the quantities of alcohol and other elements contained in fair average samples of one imperial pint each of eight different kinds of wines commonly consumed in our region:[2]

Name of wine.	Alcohol (absolute).		Tartaric and other fixed acids.	Acetic acid.	Sugar.		Ethers.	Mineral matter.
	Oz.	*Gr.*	*Gr.*	*Gr.*	*Oz.*	*Gr.*	*Gr.*	*Gr.*
Hock	1	219	39	18	None.		4	16
Claret	1	306	31	18	None.		6	18
Champagne	1	343	20	10	1	120	5	20
Burgundy	2	18	24	17		10	6	18
Carlowitz	2	35	36	19	None.		5	16
Sherry	3	147	24	12	0	236	4	38
Madeira	3	218	26	18	0	175	5	33
Port	3	218	23	12	0	359	6	20

The principal constituent, aside from water, of whiskey, rum, and brandy, like wine, is alcohol, which indeed is the princi-

[1] Church, op. cit., p. 190.
[2] Idem., p. 194.

ple of primary importance in all alcoholic beverages. The whole class, therefore, and especially in view of the subject we have under consideration, is to be considered in respect of its effect upon the central nervous system and not in regard to its nutritive value.[1] It has been observed by people from aforetime that alcohol in its first effects usually, though not always, increases the activity of mind and body: the senses apparently become more acute, checks upon speech are released, and bodily movement is augmented. This phenomenon has been ascribed to the exciting influence of alcohol upon brain cells; it has been thought to act directly upon the perceptional, ideational, and motor regions, inciting them by a kind of irritation or inspiration, to heightened and intensified action. But we get a different conception of the case if we look at it from the point of view of modern neurology. At the risk of wearying the reader, I repeat that an important part of the nervous mechanism is concerned with co-ordinating the activities of mind and body. Higher and more differentiated centers control and correlate lower and more fundamental ones. Now it seems that the influence of alcohol in the organism may be explained most satisfactorily by supposing that it has a general paralyzing effect upon nerve structures, first attacking the inhibitory system and nullifying its restraining power. This produces temporary exaltation when one is depressed and a general increase in activity due to the rebound of the system from the constriction that had been placed upon it. But it is well known that as the influence of alcohol increases in the organism the higher mental processes and the more delicate motor co-ordinations are soon attacked; and ultimately even the most fundamental functions are paralyzed when both mind and body fall into a wholly disorganized condition. Intoxication means, considered from one point of view, the temporary destruction of psychical and physical functions which it has taken nature

[1] Since the above was written I have read Prof. Atwater's Report to the Middletown Scientific Association in which he takes the view that alcohol is a food; but he would, I believe, agree to the statement I have made that its effect upon the nervous system is after all the vital matter for every one of us.

an infinitely long time in the process of evolution to elaborate. One would certainly not be extreme in saying that an intoxicated person returns to the estate of the brute, since while he is in this condition the higher cerebral structures, those which have been built in the last stages of the evolutionary process, through which are manifested the highest attributes of the human mind, are rendered inactive, and the individual lives for the time being upon a lower plane, when old reflex arcs again become complete and have their way. If from the point of view of science there are such creatures as fools, then a man, and especially a student, who will deliberately become drunk, must certainly be catalogued in this group. Let it be remarked in passing that no more pitiable or grievous spectacle can be witnessed than that which is presented when a number of university men, in whom should be evidenced the glory and triumph of evolution, and who above all others should be the last to yield mental poise and balance, its supremest blessing,—when such men forfeit the right to manhood and voluntarily bring upon themselves dissolution, intellectual, emotional, and physical.

The view which is here presented of the neurological influence of alcohol as a paralyzing agent upon nerve action and control is not a wholly new one. I find that the eminent physician Harley arrived at this opinion some years ago, approaching thereunto by a different route from that taken above. He says:[1]

"Alcohol, when taken in small quantity, is in general said to act as a direct cardiac stimulant, and its stimulating effect is supposed to be due to its possessing the faculty of increasing the muscular power of the heart. I take an entirely different view of the matter, and shall now endeavor to show how the increase in the force of the heart's movements, the quickening of the pulse, the flushing of the face, the congestion of the retinal blood-vessels, as well as all the other visible appearances of accelerated cardiac functional activity, are in reality in no wise due to the stimulating action of alcohol, either on the heart's muscular tissue or the nerves supplying it, but actually to the very reverse—namely, its paralyzing effects

[1] Popular Science Monthly, Vol. 33, pp. 191–199.

on the cardiac nerve mechanism. Destroy or paralyze the inhibitory nerve-center, or arrest its power of communicating with the heart by dividing the vagus, and instantly its controlling effect on the cardio-motor mechanism is lost, and the accelerating agent, being no longer under its normal restraint, runs riot. The heart's action is increased, the pulse is quickened, an excess of blood is forced into the vessels, and from their becoming engorged and dilated the face gets flushed and the retina congested—all the usual concomitants of a general engorgement of the circulation being the result.

"The relative effects of alcohol and opium were found to be as follows:

In 100 parts of air.	Oxygen.	Carbonic acid.	Nitrogen.	Vol. at O. C. at 1 metre pressure.
Composition of employed air	20.9	0.002	79.038	30.96
With pure ox-blood	10.58	3.330	86.09	14.91
With pure ox-blood 5 per cent. of alcohol	16.59	2.380	81.03	18.97
With pure calf's blood	6.64	3.47	89.89	10.11
With pure calf's blood .005 grm. of morphia	17.17	1.00	81.83	18.17

Dr. Gaulé,[1] of the University of Zurich, has advanced a somewhat similar opinion of the influence of alcohol in considering its relation to happiness; and his views are eminently suggestive to the student who fancies that an efficient way to meet difficulties is to forget them or imagine them out of existence or of less consequence and importance than they really are, by maiming those powers of the mind that give an accurate description of situations as they actually exist.

"* * * So the influence of alcohol is exactly as if the brain were cut away. The man no longer stops to consider the whole situation, to make use of impressions of former experiences stored away in the brain, or weigh present obligations. How does it increase the feeling of happiness? The body uses its powers in resisting the outside forces which act upon it. Normally, there is a balance between body and environment. If environment prevails we are discouraged; and if we are able to prevail, our spirits rise and our happiness grows. And it is not for the moment only, but we compare the accumulated impressions of the powers outside of us with the powers which our brains develop, and are happy or unhappy according as we feel our superiority or otherwise. Just how much does alcohol interfere in this balance of powers? It clearly cannot lessen the power of outside

[1] Popular Science Monthly, Vol. 46, pp. 30–31.

influences which harm us; it can as clearly not increase our own powers in so far as they enter into this conflict with the outside world—it rather makes us less skillful and able. What can it do, then? It can deceive us. It dulls our appreciation of powers outside of us until they seem so much smaller that we are sure we can conquer them, and so we gain a feeling of satisfaction."

Wilson[1] has shown most conclusively that the drunkard is simply a person in whom has become permanent the inco-ordinations, the lack of control which is always induced temporarily by any single spree. The balance-wheel is thrown out of gear for good. The man is a creature of impulse, and that unfortunately of a low type; the regulating, the subduing, really the spiritual mechanisms of his being, have been paralyzed so often that they are at last rendered permanently inactive. This extreme case is cited simply to throw into clearer light the ordinary effects of alcohol, which, although when taken in small quantities may never produce great damage to the organism, yet there must always be grave danger in its use. Maudsley, after lifelong study of the causes of mental derangement, has much to say[2] of the baneful influence of this agent; and Mercier, a student of insanity too, is unsparing in his condemnation of alcohol, and a few of his words[3] may be quoted in support of the views presented in these paragraphs,—that alcohol is a factitious force-producer, and when used habitually results eventually in the dissipation of energy, and sooner or later disturbs the delicate mechanisms by which the organism is held under the control of a vigorous will.

"Ask a man who has just left a city dinner to settle with you the lease of a house, or a deed of partnership. He will naturally refuse. If you press him, he will say that it is not a proper time to transact business; and, if pressed further, will explain that to take him now is unfair, for to such an important and delicate matter one must come with a clear head. The admission is that the mind is not now as vigorous as it will be tomorrow morning. There is a slight enfeeblement. Partly from the fatigue of the day, partly from

[1] *Drunkenness*, Part I. See also Richardson, *Ten Lectures on Alcohol*, pp. 123–179.

[2] See *Responsibility in Mental Disease*, pp. 285–286.

[3] *Sanity and Insanity*, p. 316.

the effect of the dinner in drafting off a part of the blood supply from the brain to the stomach, but chiefly from the benumbing effect of the alcohol that he has imbibed on his highest nerve regions, his mind is not as clear nor as vigorous as it is wont to be. The confusion is not great; he can make an after-dinner speech of average intelligence, can reckon his legal cab fare, and so forth, but he will not trust himself to settle a delicate matter of negotiation. He feels that the keen edge of his intellect is blunted. It is the very highest of all his intellectual faculties that have been dulled. Similarly on the bodily side—he can walk perfectly straight, can light a cigar without bungling, and button his overcoat with facility; but when he tries to play billiards he finds 'his hand is out.' He is not certain of his strokes. He can no longer regulate his movements with the nice precision that is required for success. Of bodily, as of mental capabilities, he has lost the most elaborate, the most delicate, the most precise. At the same time that he shows these signs of defect in his highest nerve arrangements, he shows some sign of overaction of somewhat lower arrangements. By the annulling and placing out of action of the highest, control is removed from those just below the highest, which are consequently 'let go' and tend to over-act. The staid and self-enclosed man of business becomes an expansive, jolly companion. He gets on back-slapping, rib-punching terms with his convives. He tells little anecdotes about his past career, with winks, and wheezes, and warnings that they are not to be repeated to his wife. His discretion and reticence are diminished by the loss of his highest centers and he exhibits a phase of character inferior to his usual standard. No one would call this state of things insanity; but for all that it is the beginning of a process which, if continued, would become insanity. It is the point at which divergence from the processes of health begins to occur. It is not insanity, but it is the rudiment of insanity. Let us trace the process further and see what it develops into."

When one looks at this subject from the standpoint of education he sees that the university student less than any one else should need to quicken and intensify the psychic life by the employment of an artificial excitant. While it is the testimony of those who should know that the initial effects of wine are stimulating to thought and feeling, and there is a general buoyancy and perhaps elevation in the entire being, yet this advantage can be secured in other ways more normal and therefore more beneficial to the finest quality of mind. That mental

exaltation which results from the enjoyment of beautiful art and music and intercourse with inspiring people can readily beget that fine ecstacy which has made wine so celebrated in song and story. There is surely more of lasting joy in becoming drunk with grace and beauty than with wine; beauty exerts an integrating influence, it adds to the vitalities of life; while wine disintegrates and dissipates energies. Considering that the university student has special obligations to the commonwealth by whose bounty he is receiving the blessings of education, then he above all others should secure his mental gladnesses and gayeties through means which will confer upon him increasing power and balance rather than through those alluring agents which may momentarily give pleasure but which in the end are destructive rather than constructive.

The value of any food must be determined in a final analysis by its force-producing capabilities. If beer, wine, and whiskey impart energy to the organism this should be revealed in increased activity of mind and body. Research has shown in some measure at any rate that instead of alcohol thus augmenting the amount of work which an individual can do, it actually reduces it. Martin[1] observes that the evidence adduced by competent observers is distinctly against the use of spirits by soldiers in time of war. He says there is no cogent evidence to show that alcohol is of service in sustaining bodily activity. Hodge's investigations are of especial significance on this point. Professor Hodge was enabled a few years ago to conduct a series of experiments under the auspices of the Committee of Fifty for the study of the liquor problem, wherein he carefully observed the mental and physical effects upon a number of dogs of alcohol administered in the forms of beer, wine, and whiskey. The results so far as they refer to the particular topic under discussion—the value of alcohol as a force producer in a living organism—may be presented in his own words:[2]

"During the second month after administration of alcohol spontaneous activity of both Tipsy and Bum became noticeably impaired.

[1] *Treatise on Hygiene*, Stevenson & Murphy, Vol. I, p. 487.

[2] Popular Science Monthly, March and April, 1897, and reprint.

This gradually and steadily increased until, last spring, it seemed to me from daily observation that the alcoholics were not much more than half as active as the normals. How to secure an objective expression of this fact presented some difficulties at first. To put them in large recording cages, such as we use in the laboratory to study the daily activity of rats and mice, would clearly be an imposition on a dog's good nature, and would possibly suppress his activity in proportion to his intelligence. To watch four dogs during the twenty-four hours would require four observers, and their presence would be a disturbing factor.

"Pedometers were thought of, but none could be found suitably constructed for use with the dogs. Finally, Waterbury watches were obtained, and, by removing the hair springs, weighting the balance wheels unequally, and by proper adjustment of buffing pins so that the balance wheel could move just far enough to release the escapement, a watch resulted which ran only when shaken. After a month of preliminary trials an adjustment was attained so delicate that the watch could hardly be jarred so slightly as not to release the escapement one tooth, and the two could be shaken, violently or gently, and in any position for an hour at a time (fastened firmly together) without showing a variation of more than two seconds on reading the hands.

"The watches are now placed in stout leather pockets in specially constructed collars and the dogs allowed to wear them. * * * The watches were read every evening at exactly six o'clock. Bum is seen to develop seventy-one per cent. of Nig's activity, and Tipsy only fifty-seven per cent. of Topsy's.

"The watches, of course give us only the total quantity of spontaneous daily movement of each dog with no indication as to its quality. Something to give a qualitative expression of strength, ability, and resistance to fatigue was devised, which consisted in a series of competitive tests at retrieving a ball. The balls were thrown in rapid succession across the university gymnasium, one hundred feet, and a record was kept of the dogs that started for it and of the one that succeeded in bringing it back. One hundred balls constituted a test, and to throw them consumed about fifty minutes.

"In the first series, consisting of 1,400 balls thrown on successive days, January, 1896, the normal dogs retrieved 922, the alcoholics 478. This gives the alcoholics an efficiency of only 51.9 per cent. as compared with the normals. Bum's ability in this series as compared with Nig's is only thirty-two per cent. (See Fig. 18.) It was also noted that Bum and Tipsy were much more easily fatigued than the normals.

"A second series, of 1,000 balls, November, 1896, in which Bum and Nig, were tested, gave similar results. Nig shows fifteen per cent. of Bum's fatigue. Expressed in other words, Bum lies down to rest 6.7 times to Nig's once."

In discussing the results of these experiments, Dr. Hodge quotes Professor Gaulé to the effect that once during the strain of his *Staatsexamen* he suddenly stopped his wine and beer and was surprised to find how much better he could work. An eminent Leipsic professor has said that German students could do twice the amount of work if they would let their beer alone. Dr. August Smith found that moderate doses of alcohol not sufficient to intoxicate lowered psychic ability to memorize as much as seventy per cent.[1]

From whatever position, then, we regard the influence of alcohol upon the force-generating power of the organism, we find on every occasion that it has only a deleterious issue, except of course when it is employed as a therapeutic agent.[2] The practice in which students ofttimes indulge of exciting good cheer by a few glasses of beer or wine must certainly in the long run lessen the efficiency of mind and body. When a great feat is to be undertaken, as upon the football field, alcoholic beverages are absolutely prohibited the contestant. A student should regard his daily tasks as all being great ones for which he must prepare himself most effectively mentally and physically. The ordeals of the student in his immediate classroom duties and in the more important businesses of post-university life should demand as clear and vigorous a brain and as agile and serviceable a body as the athlete requires to meet the difficulties which he will encounter in the arena.

§ 4. *The Influence of Tobacco Upon the Production and Expenditure of Force in the Organism.*—While alcohol operates to throw off the brakes which nature places upon the organism

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[1] Hodge, op. cit., p. 25.

[2] Atwater's investigations already referred to seem to present alcohol in a more favorable light. Small quantities of alcohol are not injurious, says Atwater, but yet there are grave dangers in its use, since it is difficult for the habitual drinker to avoid excesses.

when danger is sighted ahead, tobacco seems to have a directly contrary influence. It is the common testimony of smokers that after a day of severe labor or intense excitement or exertion of any kind, when the mind is chaotic, uncontrolled, and repose is impossible,—in such an event, the cigar or the pipe has a soothing, calming effect. Nicotine seems to act as a stimulant to the inhibiting centers of the nervous mechanism. In view of this well known action of tobacco, it can be seen why in cases of fatigue when the mind cannot be held in check and energy is being wasted despite efforts at conservation,—in such a situation tobacco must be regarded as a conserver of force. It aids the organism to get hold of itself, to become controlled. This is especially true when, as smokers so frequently testify, tobacco skillfully wooes Morpheus when nothing else will entice him to one's bedside.

But this does not of necessity imply that tobacco is a valuable auxiliary to the student's dietary. It is not too much to suppose that under normal and healthful conditions a student will rarely reach the point where he will need any other sedative agent than that furnished by an abundance of nutritious food, vigorous exercise, and refreshing sleep. As a matter of fact, though, our young men taken as a whole do not smoke because they feel the need of the soothing influence which it affords; they smoke because custom dictates it. This is evidenced by the irrational way in which they do it; and it is suggestive, too, that practically all of the law students who replied to our questionnaire smoke, while about 55 per cent. of the "Hill" students are "abstainers." To smoke immediately after breakfast is as foolish as it is useless; for at such a time tobacco rather hinders than helps the organism to accomplish the tasks before it; except possibly in those instances when the system has become so permeated with nicotine that it is, in common with the well-known effects of opium, creating an abnormal desire which is unrelenting every hour and minute of waking life. As Richardson well says in his Diseases of Modern Life:[1] When mental labor is about to be undertaken a pipe

[1] P. 316.

produces in the majority of people a heavy, dull condition, which impedes digestion and assimilation, and interferes in some degree with that "motion of the tissues which constitutes vital activity." But when the mind is occupied for a long time, so that exhaustion supervenes, a pipe gives to some *habitues* a feeling of relief; it soothes, it is said, and makes possible clear thinking. Few men become so habituated to the pipe that they can begin the day well on tobacco. "Many try, but it almost invariably obtains that they go through their labors with much less alacrity than other men who are not so addicted."

CHAPTER V.

THE PREPARATION OF FOOD—HOURS FOR MEALS.

§1. *The Philosophy of Cookery.*—While the composition of a food is an important factor in determining its worth, yet a more important factor still, perhaps, is the manner in which it is prepared for use in the organism,—the manner in which it is cooked, that is to say. This is seen to be true when it is realized that man is a cooking animal, and as such is distinguished from the rest of creation. It seems to be clearly revealed in his constitution that he was not designed to take into his stomach in the raw condition in which they are found in nature most of the articles which constitute his dietary. He is not a graminiverous animal; he lacks the long alimentary tract, the special stomach, and the apparatus for secreting large quantities of saliva which is possessed by the cow and other grain munchers. The crops of birds probably fulfill somewhat the same function in the digestive processes that the second stomach does in the ruminants; and in both cases this elaborate apparatus is necessary in order to transform starch and other food elements into assimilable products. Again, man does not appear to be adapted to eat meat unsubdued by heat; sentiment if nothing more would forbid his doing this. The human species has progressed to the point in the evolutionary scale where it can call to its aid forces which are capable of advancing foods as they are found in their native state far along in the process of digestion, so that when taken into the system they may be assimilated with comparatively little delay or expenditure of vital energy.

It may be observed in passing that in all likelihood this accomplishment more than any other has contributed to the rapid mental progress and present superiority of mankind. Spencer[1]

[1] *Education*, chapter on Physical Education.

has pointed out that animals which live upon coarse, indigestible foods, as the cow and the sheep, are, considered in respect alike of physical power and mental acuteness and vivacity, relatively inferior in the scale of being. Now, it seems a safe inference from the evidence everywhere at hand that the quota of energy which can be expended in mental and physical activity will be determined by the ease with which this may be obtained in the process of nutrition. It is a fact of daily experience, probably as common in student life as elsewhere, that when the stomach is overloaded with indigestible and waste materials the mind is inert and confused, and the body little disposed to vigorous or lively activity. Let any one recall his mental and bodily status after assisting at the ordinary Thanksgiving feast, or perhaps even the familiar Sunday dinner. Sabbath afternoon is so frequently a time for loafing in both body and mind, not because one wants to rest but because he cannot arouse himself. Many of our students have a still more impressive experience; not infrequently they are required to rush off precipitately to their university duties directly following upon a meal which taxes the organism to the utmost,—oatmeal cooked a half hour or less, fried potatoes, fried meat or eggs, hot bread and cakes, and coffee,—a combination which, as will be shown later, is more than a match for the most energetic and powerful digestive mechanism. At such a time the mind works slowly and inaccurately; and the philosophy of the thing is not at all abstruse. When food is taken into the system the organism will if necessary turn its energy wholly to extracting the nutrition contained therein. Suppose then that a considerable amount of half digested starch and other food materials find their way to the stomach; there is needed at once force to transform these into assimilable substances. The blood, rushing to the appropriate organs to supply the required digestive agents, must, of course, be withdrawn from the service of the cerebral and muscular systems. When, on the contrary, food is eaten which is nearly ready for assimilation, the organism can while attending to the now easy labor of digestion engage also in a measure in mental or physical work.

§2. *Modes of Cooking. Local Practices with Criticisms.*—As has been said, the primary purpose of cooking is to advance the assimilability of foods as they are found in the raw state so as to relieve the digestive apparatus of much arduous drudgery. For the most part this is accomplished by applications in one form or another of heat. In the cookery of meats it should be the aim to soften tissues and develop flavors which will excite digestive juices; and those modes will be most efficient which will attain these ends while not destroying the nutritive properties. In roasting, baking, and broiling heat is applied directly to the surface of the meat; whereas in boiling and frying it is conveyed by convection, in the first instance through water, in the second through oil. Now, one of the most valuable elements of meat, albumen, exists in considerable quantities as a juice; and this escapes with comparative ease in boiling when the meat is put into cold water and gradually raised to the boiling temperature. When the meat is thrust into boiling water at the outset, however, the pores in the surface become closed in such a way as to prevent in a large degree the loss of the juices, and the cooking may proceed with comparatively little waste. The most economical modes of cooking this article, though, are those in which a high degree of heat is applied directly, as in baking, broiling, or roasting. Frying is the most objectionable method of all, and especially the sort of frying which one finds in the average boarding-house or even in the majority of homes. Here the cook places a little oil in the bottom of the frying pan "to keep the meat from sticking to it," and heats it to a point at which the fat is partly decomposed; she never imagines that in frying cooking should be accomplished in the same way as in water except that a different medium is used. What is to be secured is the transmission of heat through the oil. Cooking in this way would not be so objectionable if a *bath* of fat were used instead of a little in the bottom of the frying pan; although even here food is liable to be made indigestible by becoming fat soaked, so to speak. It is of course well-known that the fat which incases the nutritive elements in fried meats, eggs, and

the like digests lower down in the digestive tract than the substances themselves, so that these latter are held in the stomach for a long period, resulting usually in fermentation, and greatly overtaxing the stomach.

An examination of the returns from our questionnaire shows that meats, potatoes, eggs, and cakes are as often fried as cooked in any other way; and this cannot but be regarded as a very serious defect in local practice. And I know from personal experience that the frying which is done in some places here renders the food highly indigestible. A breakfast of fried pork, fried eggs, fried potatoes, fried pancakes, and doughnuts must very successfully prevent for several hours vigorous activity in the head of almost any student. There is no danger in saying emphatically that food prepared in this way is unfit for the needs of a student or, in fact, of any civilized being; and it may not be out of place to observe that the state is bestowing its favors in an unprofitable manner in attempting to educate an individual who habitually regales himself on fried stuffs, and especially such a variety as the landlords in our locality provide for their guests.

But the cooking of meats, bad as this is even, is not so defective in Madison boarding houses, as the cooking of starch foods,—the cereals, bread, vegetables, cake, and the like. It has previously been indicated that starch in order to be incorporated into the system must become converted into dextrin. This is accomplished in the ordinary process of digestion by insalivation, wherein the active digestive principle of saliva is brought into contact with the starch granules of food. Starch may, however, be digested in other ways. It is well known, for instance, that the nitrogenous principle, diastase, obtained in malting, possesses the power to carry starch along through several of the stages essential to complete conversion into dextrin. It is also known that digestive changes may be wrought by the application of dry heat to starch. If you place starch granules in an oven heated to the temperature of 300°, they

are not apparently affected at all; but if you increase the temperature 100° or thereabouts they will suddenly be transformed into dextrin. The change is an isomeric one, for dextrin is of the same composition as starch.

Now, the primary purpose in cooking the starch foods placed on our tables should be to convert the starch so far as possible into dextrin. Starch, as it is obtained in grain foods, cannot be converted into dextrin without subjecting it for a long time to heat, either directly or through convection in cooking in water. The boiling of raw oatmeal for say thirty minutes will not in all probability suffice to carry the starch far along in the process of digestion, and this work must be completed after the food is taken into the stomach if much nutritive value is to be derived from it. On the other hand, if the cooking had been carried on for a longer period less would have been left for the stomach to do, which is the great object to be attained in the cooking of these foods,—the relief of the digestive apparatus. The processes essential to complete starch digestion have been excellently set forth in a pamphlet presenting the results of experiments prosecuted in the food laboratories of the Battle Creek Sanitarium, in which it is shown that "water-brash" and other dyspeptic symptoms so common among the Scotch Highlanders is due to the excessive use of "Scotch brose," which is simply raw oatmeal stirred up in hot water. The prevalence of indigestion in our own country, too, is due principally to the same cause,—the use of starchy or cereal foods in an uncooked or imperfectly cooked condition. The pamphlet goes on to say that:

"The bread of the olden time consisted of thin cakes formed from a mixture of flour and water, well kneaded and baked on a tin or stove kept hot by a glowing fire. Bread prepared in this manner is ready for prompt digestion and assimilation.

"The transformation of starch into sugar—in other words, the digestion of starch—takes place by stages. The starch is first converted into

"(a) Amylo-dextrine, or soluble starch. This is the form in which it is found in well-boiled paste and in ordinary baker's bread, in so-called ready-cooked breakfast cereals, and in mushes, gruels, vegetable soups, and similar preparations of starch.

"The third stage is that of (c) achröo-dextrine, that in which the starch is found in such perfectly cooked cereal foods as zwieback, granose, and granola, and in the outer browned portion of the crust of bread.

"In the second stage (b) the starch is further transformed into erythro-dextrine, the form in which it is found in what might be termed the half-cooked condition of well-baked ordinary baker's bread, in crackers, rolls, gems, and similar foods.

"The fourth stage is maltose or sugar, the final results of starch digestion. The digestion of starch is accomplished in nature by the action of so-called ferments or diastases. These are found abundantly in both the animal and vegetable kingdoms,—in animals in the saliva and other digestive fluids. In grains, the starch digesting ferment or diastasis is found just beneath the bran, ready to form sugar for the nourishment of the young plant. The starch found in green apples and other fruits is, by the process of ripening, converted first into the various ferments or dextrines exclusively, and finally into sugar.

"The formation of the last form of dextrine is indicated by the appearance of a slight brownish color in the digesting mass. One additional step only is necessary to convert the starch into sugar. Heat is not capable of producing this step in the process, but when achröo-dextrine, the last stage of heat digestion, the perfectly cooked starch is brought into contact with the saliva of any other starch-digesting ferment, the formation of sugar takes place instantaneously. In other words, by the application of heat of sufficient degree for a sufficient length of time starch may be converted first into amylo-dextrine is produced by a temperature sufficient to cause the hydration or gelatination of starch in the formation of paste by cooking of starch or flour. Longer cooking, or cooking for a short time at a temperature above the boiling point of water, advances starch one step along in the process of digestoin to the stage of erythro-dextrine. Exposed to still higher temperature for a proper length of time produces achröo-dextrine.

"Raw starch, on the other hand, when exposed to the action of the saliva is not changed at all. Slightly cooked starch, that is, amylo-dextrine or fluid starch, is converted into sugar only by the prolonged action of the saliva. Erythro-dextrine, or imperfectly cooked starch, is converted into sugar somewhat more quickly by the action of the saliva, but in achröo-dextrine, or perfectly cooked starch, the transformation takes place as soon as it is brought into contact with the saliva. It is for this reason that a brown crust of bread, zwieback, and well-toasted granose develop a distinctly sweetish taste when chewed.

"Our modern methods of bread-making, in which the dough is formed in large masses or loaves, or small masses under the name of biscuits, buns, rolls, etc., present the starch or farinaceous elements of cereals in a half-raw, imperfectly cooked condition, prepared to interfere with digestion, rather than to promote this most important vital process. Half-cooked mushes and porridges assist in the work of mischief, and as a result, the American people have come to be almost universally afflicted with amalaceous dyspepsia, or starch indigestion. This fact explains the extensive use of malt preparations, and the recent introduction of various starch-digesting ferments or diastases of various origin, some of malt, others from vegetable fungi."

It is then to be very greatly desired that those who provide food for students should take especial care in the cooking of cereals and breads. While it is of supreme importance that whenever starch foods are eaten they should be thoroughly cooked, yet this is especially necessary in respect of the morning meal when a stomach full of half cooked starch will be a serious drawback to the student during the best hours of the day. It may as well be recognized that no matter how skillful the teaching it must fall on barren soil if it is received by those who are devoting all their strength to breaking up starch.

Foods, as for instance, Malt Breakfast Food, Granola, etc., are now being manufactured which are either subjected to the degree of heat necessary to carry starch quite a ways along in the process of conversion into dextrin, or the same end is attained by malting; and these, it seems, should be found more freely upon the tables of students than is indicated in our returns. I have, however, spent some days at one boarding house in the city where the morning cereals seemed all thoroughly cooked, and were most palatable and nutritious; but I have obtained dishes at other places where students board that were not fit for mortal man to entertain in his system. The freer use of thoroughly baked, or better still twice baked bread, is much needed in our community. In the baking of bread in the ordinary way the middle of the loaf does not rise above 212°, although the outside reaches 400° or more. Many people choose the crust for its more agreeable taste, which results from the conversion of the starch into dextrin by the ac-

tion of heat in baking. It is at the same time more digestible, and so in reality more nutritious.

A word should be said respecting the cookery of one or two other common articles of food—and first, potatoes. The usual mode in our own locality is to boil them peeled and mash them. Now, one of the most valuable nutrient elements in the potato is the salts of potash, which in a jacketless potato readily escapes into the water during boiling, and especially if the tubers are placed in cold water at the outset. Jackets or no jackets then is the vital question, and we are compelled to decide in favor of the affirmative. In countries where the people cannot obtain these salts in meats and other foods, experience has taught them to cook the potatoes always without peeling. Baking, though, is altogether the most desirable mode of cooking the potato. By this method all the salts are preserved; while in boiling, even with the covers on, the potato suffers some loss. It is very evident from our returns that a reform is needed in the cooking of such a substantial and yet simple article of food as the potato.

It is probable that one of the most poorly cooked foods in our locality is the egg. The method is almost universally frying. To say nothing about the chemical changes which this produces, it is enough to point out that the albumen becoming incased in animal fat partially decomposed is well nigh invulnerable to the attacks of the digestive juices. On the other hand, anyone who has tried immersing an egg for eight minutes or so in water about twenty degrees below the boiling point and which has been taken off the stove, will know that no part of the egg is cooked hard and yet heat has penetrated throughout the whole. An egg cooked in this way is highly digestible and possesses a delicious flavor; for a morning meal it will supply the energy needed for the day's work much more speedily and with less expenditure of internal forces than a fried egg or an egg *boiled* in water at a temperature of 212°.

§3. *Hours for Meals.*—It is well known, of course, that a heavy meal makes demands upon the energies of the system for a considerable period; mind and body alike are less efficient while the early stages of digestion are in progress. The prosperity of digestion itself requires muscular repose for a time; and when three "square" meals are disposed of daily a relatively large part of waking life must be devoted to the interests of the stomach, and the head and hands must suffer thereby. It would seem a much wiser scheme, and one which is being adopted now in the cities especially, to get most of our nutrition in two repasts; and if we have a third, to make it exceedingly light so that it will not interfere seriously with either mental or physical activities. A business man in the city would not think of dining at midday; he lunches simply, and his luncheon really serves the purpose of a little recreation rather than of gaining nutrition.

Our students enjoy three meals a day, all of about the same proportions, so far as can be judged from the bills-of-fare. It is true they have at noon, with a very few exceptions, what is called dinner, and this is supposed to be the principal repast of the day, although it seems to be so only in the sense that perhaps heavier and more indigestible viands are discussed. But a large number of our students attempt their hardest work in the afternoon immediately following their experience at table; their study hours are in the majority of cases from 2 to half past 5; and it is surely not an overstatement to say that no brain is in good workable condition when handicapped by a stomach full of such things as are indicated in the midday bills-of-fare given in Chapter III. Nearly every one of our students —all except fourteen—reported that from 2 to 4 was the dullest time in the entire day. From 7 to 9 is also a period of marked mental depression. One would suppose that the mind would be worn out as the hour for retiring approached, and that it would be most obtuse then; but only eight out of the whole number of students reporting said they were dullest at bedtime; the others were stupidest after meals.

A reform in respect of the hours for gaining nutrition is assuredly needed in our community. It would seem as if the majority of those who make a business of boarding students make no business of it at all. If they were engaged in any other calling they would be obliged to minister to the well-being of those whom they served; but not so with most of the landlords and landladies who care for students. So many people seem to harbor the opinion that a student's welfare does not need special consideration anyway; it is an easy thing to study and the question of special food and appropriate times for eating is of little importance. But we need to have present practices modified so that students will at midday have a light luncheon of very digestible and nutritious foods; then at half past five or thereabouts should come a more substantial meal, perhaps the principal one of the day. It should be said in this connection that the last repast ought not to be eaten much later than this, since it is important that the digestion of this meal should be completed before bedtime. The stomach is not active during sleep, and foods remaining therein during the night are certain in most instances to pass through fermentative processes, seriously disturbing the normal functioning of the digestive system. Hardly any one can discuss a late banquet without his tongue the next morning revealing his dissipation; the germs which have been prospering during the night have installed themselves in every part of the mucous membrane which is accessible to them.

At Columbia University most of the students partake at midday of a simple luncheon of milk and bread, and perhaps a sandwich, obtained at the University refreshment stand; and after an hour's social chat, go back to their work in the library and laboratories. This seems a much more rational way than to rush headlong home to a big dinner and rush back in the same manner to recitations and other work, or escape to one's room to doze away two or three profitless hours. This gives one both a bad stomach and a bad conscience, and results eventually in an empty head. May we not hope that some day there

will be near the campus of our University a refreshment booth offering the most wholesome, palatable, and nutritious foods at slight cost, so that students may spend in the library, in the laboratories, and in general social intercourse on the campus the time which is now wasted in rushing to a "square" meal and recovering from the same?

During the winter of 1892–93 an experiment was made along this line at the Boston School of Gymnastics in serving luncheons to women students at 15 cents each. The manager, Miss Wentworth, kept a record for one month of the amount of foods furnished, with their nutritive values; and while I believe more nutritious and more easily digested articles, as I have indicated in Chapters III and IV, could be furnished now than appeared in this record, yet it is suggestive regarding what could be done for students in our midst without departing in any way from established custom respecting articles of diet.

Statement of one month's luncheons served to students (women) five days in the week, beginning February 1, ending February 28. (Atkinson, op. cit.)

	Ounces.	Food Value in Grams.			Calories.
		Proteid.	Fat.	Carbohydrates.	
February 1st:					
Beef broth	9.4	2.63	20.4	128.4	817.5
Two rolls	4.0				
Gingerbread	4.0				
Butter	0.7				
February 2d:					
Baked beans	8.4	2.63	35.6	131.4	979.3
Brown bread	2.0				
One roll	2.0				
Butter	0.7				
One orange	5.5				
February 3d:					
Escalloped meat	10.0	32.2	26.8	138.8	942.2
Rolls	4.0				
Butter	0.7				
Apple sauce	5.3				
February 6th:					
Vegetable soup	9.7	20.0	20.9	92.1	648.2
Rolls	4.0				
Butter	0.7				
Apricot sauce	6.0				
February 7th:					
Potato soup	9.6	15.0	24.9	131.5	826.1
Rolls	4.0				
Butter	0.7				
Two baked apples	8.0				
February 8th:					
Pea soup	9.8	23.6	35.4	126.1	935.3
Rolls	4.0				
Butter	0.7				
Apple cake	4.0				
February 9th:					
Beef hash	6.4	33.1	24.0	136.5	911.8
Rolls	4.0				
Butter	0.7				
Apple sauce	5.3				
February 10th:					
Oyster soup	9.6	20.9	25.9	108.0	762.5
Rolls	4.0				
Butter	0.7				
Prune sauce	5.3				
February 13th:					
Beef croquettes	4.0	16.8	22.7	111.4	738.8
Potato croquettes	4.0				
Rolls	4.0				
Butter	0.7				
Baked apples	8.0				
February 14th:					
Fish chowder	10.0	22.2	30.0	101.2	778.1
Rolls	4.0				
Butter	0.7				
One orange	5.3				

Statement of one month's luncheons served to students (women).—Continued.

	Ounces.	Food Value in Grams.			Calories.
		Proteid.	Fat.	Carbohydrates.	
February 15th:					
Tomato soup	9.7	19.1	26.3	103.0	739.0
Rolls	4.0				
Butter	0.7				
Doughnuts	3.5				
February 16th:					
Escalloped fish	4.0	26.8	24.0	109.8	777.2
Rolls	4.0				
Butter	0.7				
Baked apples	8.0				
February 17th:					
Baked beans	8.4	26.3	35.6	131.4	979.3
Brown bread	4.2				
One roll	2.0				
Butter	0.7				
One orange	5.3				
February 20th:					
Corn soup	9.6	13.6	23.1	107.0	704.2
Rolls	4.0				
Butter	0.7				
Apple sauce	5.3				
February 21st:					
Beef broth	9.4	26.3	20.4	128.4	817.5
Rolls	4.0				
Butter	0.7				
Ginger-bread	4.0				
February 22d:					
Baked beans	8.4	26.3	35.6	131.4	979.3
Brown bread	4.2				
One roll	2.0				
Butter	0.7				
One orange	5.5				
February 23d:					
Escalloped oysters	4.5	24.0	34.0	115.2	880.3
Rolls	4.0				
Butter	0.7				
Buns	5.0				
February 24th:					
Tomato soup	9.7	15.0	19.5	108.4	681.8
Rolls	4.0				
Butter	0.7				
Baked apples	8.0				
February 27th:					
Potato soup	9.6	19.1	24.9	139.7	875.9
Rolls	4.0				
Butter	0.7				
Lemon jelly	6.0				
February 28th:					
Pea soup	9.8	23.6	35.4	126.1	935.3
Rolls	4.0				
Butter	0.7				
Apple cake	4.0				
Average	....	22.8	27.1	120.2	827.4

CHAPTER VI.

INDIVIDUAL PECULIARITIES IN DIGESTIVE CAPACITIES.

§1. *The Theory of Individual Differences.*—There seem to be two great forces that vie with one another in planning and directing the construction of every new being ushered into the world. The first is heredity, which seeks to reproduce without modification in the offspring the characteristics of the parents; the second is variation, which seeks to differentiate the young from their ancestors—to beget in them modified structures and functions.[1] As a result of the interaction of these forces it happens that while members of the human species, for instance, are much alike, still each is probably distinguished by some purely individual features either in the architecture of the body, in the workings of the vital machinery, or in mental tendency and capacity.[2] These differences are probably as marked in respect of digestive functions as of any other; and it is not difficult to appreciate this when it is realized that the transformation of food is brought about through the offices of various digestive fluids. Each food element has its particular digestive agent,—starch requiring a special one, albumen another, fat another. Now, it happens that people differ regarding the quantity and quality of each of these digestive agents; this person falls short on the one essential for the disposition of starch, another generates free hydrochloric acid in excess of that which is actually needed or which is conducive to the well-being of the organism, and so on. It results then that we all have our idio-

[1] Cf. Bateson, *Materials for the Study of Variation*, London, 1894, pp. 1–80. Darwin, *Origin of Species*, entire book; Höffding, *Outlines of Psychology*, p. 348, et seq.

[2] See for a discussion of individuality in the mental sphere,—Bain: *A Study of Character*, London, 1863; Ribot: *Psychology of the Emotions*, chap. XII; Paulhan: *Les Charactêres;* Perez: *Caractère de l'enfant et de l'homme;* Lotze: Microcosmus, Bk. VI, chap. II; Queyrat: *L'imagination chez l'enfant;* Galton; *Mental Faculty*, chap. on Mental Imagery.

syncracies regarding the articles from which we can best obtain our nutrition, and the viands we can indulge in with impunity. One who has much difficulty in dealing with starch will find it easier ordinarily to secure his albuminoids from flesh or nut foods than from the cereals or other vegetable products; although, to repeat what was urged in preceding paragraphs, by proper cooking starch may be largely pre-digested, making it acceptable to the most whimsical stomach. An acid stomach cannot tolerate sour fruits, vinegar, or other acids, while a "hypopeptic" individual enjoys and needs an abundance of fruit acids. And the principle holds in respect of many another digestive peculiarity.

§2. *Concrete Examples.*—To impress the principle of individual peculiarities in digestive powers there will be given here graphic illustrations[1] of actual analyses of the stomach fluids of two persons of the same family securing their nutrition from the same table. The analyses were made in the Laboratories of Hygiene of the Battle Creek Sanitarium according to methods devised by Golding Bird of England and Hayem and Winter of Paris, and extended and perfected by J. H. Kellogg. In the following brief explanation of the methods of examination I follow Kellogg[2] principally. In order to make the analysis it is necessary to extract the contents of the stomach after there has been eaten a given quantity of food the composition of which is thoroughly understood; and, of course, a certain amount of time must be allowed for the action of the stomach upon the food. By chemical analyses of the stomach fluids it is then possible to determine the relative amounts of the several digestive agents, and so to calculate the working power, as it were, of the stomach, indicating whether it is normal in all respects or whether it varies therefrom in regard to any of the digestive processes. In making the test at Battle Creek the

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[1] I am indebted to Dr. J. H. Kellogg and The Modern Medicine Publishing Co. for the use of the plates of the charts.

[2] *Methods of Precision in the Investigation of Disorders of Digestion*—Modern Medicine Publishing Co., 1899. Also Modern Medicine Library, No. 1, May, 1896.

GRAPHIC REPRESENTATION

Of the Results of the Chemical Examination of Salivary and Gastric Digestion.

NO. 8938.

	A'	A Total Acidity.	H Free HCl.	C Combined Chlorin.	AC Acid Combined Chlorin.	M Starch Digestion.	COEFFICIENTS OF DIGESTIVE WORK. Chlorin Liberation. m	n	Fermentation. x	Starch Digestion. b(1)	b(2)	Salivary Activity. c	Solution. y	Motility. z	
	.430	.480	.240	.410	.300	8.00	2.00	2.00	100	2.00	6.00	10.00	2.00	6.00	
	.410	.440	.225	.390	.290	7.00	1.90	1.90	75	1.90	5.00	9.00	1.90	5.00	
	.390	.410	.210	.370	.280	6.50	1.80	1.80	50	1.80	4.00	8.00	1.80	4.00	
	.370	.385	.195	.350	.270	6.00	1.70	1.70	40	1.70	3.00	7.00	1.70	3.00	
	.350	.360	.180	.330	.260	5.50	1.65	1.65	30	1.65	2.50	6.00	1.65	2.50	
	.335	.340	.165	.315	.250	5.00	1.60	1.60	20	1.60	2.25	5.50	1.60	2.25	
	.320	.320	.150	.300	.240	4.75	1.55	1.55	15	1.55	2.00	5.00	1.55	2.00	
HYPERPEPSIA.	.305	.305	[illegible]	[illegible]	.230	[illegible]	1.50	1.50	10	1.50	1.75	4.50	1.50	1.75	WELL DISINTEGRATED. RAPID ABSORPTION.
	.290	.290	.120	.270	.220	4.25	1.45	1.45	9	1.45	1.50	4.00	1.45	1.50	
	.275	.275	.110	.255	.210	4.00	1.40	1.40	8	1.40	1.45	3.50	1.40	1.40	
	.260	.260	.100	.240	.200	3.75	1.35	1.35	7	1.35	1.35	3.00	1.35	1.35	
	.245	.245	.090	.225	.190	3.50	1.30	1.30	6	1.30	1.30	2.50	1.30	1.30	
	.230	.230	.080	.210	.180	3.25	1.25	1.25	5	1.25	1.25	2.00	1.25	1.25	
	.220	.220	.070	.200	.170	3.00	1.20	1.20	4	1.20	1.20	1.75	1.20	1.20	
	.210	.210	.060	.190	.165	2.75	1.15	1.15	3	1.15	1.15	1.50	1.15	1.15	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.10	1.10	2	1.10	1.10	1.25	1.10	1.10	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.05	1.05	1	1.05	1.05	1.10	1.05	1.05	
NORMAL.	[illegible]	NORMAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.95	.95	.95	.95	.95	.90	.95	.95	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.90	.90	.90	.90	.90	.80	.90	.90	
	.170	.170	.024	.145	.130	1.70	.85	.85	.85	.85	.85	.70	.85	.85	
	.160	.160	.023	.135	.120	1.60	.80	.80	.80	.80	.80	.60	.80	.80	
	.150	.150	.022	.125	.110	1.40	.75	.75	.75	.75	.75	.50	.75	.75	
	.140	.140	.021	.115	.100	1.20	.70	.70	.70	.70	.70	.40	.70	.70	
	.130	.130	.020	.105	.090	1.00	.65	.65	.65	.65	.65	.30	.65	.65	
	.120	.120	.018	.095	.080	.90	.60	.60	.60	.60	.60	.25	.60	.60	
	.110	.110	.016	.085	.070	.80	.55	.55	.55	.55	.55	.20	.55	.55	
HYPOPEPSIA.	.100	.100	.014	.075	.060	[illegible]	.50	.50	.50	.50	.50	.15	.50	.50	IMPERFECTLY DISINTEGRATED. LOW ABSORPTION.
	.085	.085	.012	.065	.050	.60	.45	.45	.45	.45	.45	.12	.45	.45	
	.070	.070	.010	.055	.040	.50	.40	.40	.40	.40	.40	.10	.40	.40	
	.055	.055	.008	.045	.030	.40	.35	.35	.35	.35	.35	.08	.35	.35	
	.040	.040	.006	.035	.020	.30	.30	.30	.30	.30	.30	.06	.30	.30	
	.025	.025	.004	.025	.010	.20	.20	.20	.20	.20	.20	.04	.20	.20	
	.010	.010	.002	.010	.005	.10	.10	.10	.10	.10	.10	.02	.10	.10	
APEPSIA.	.000	.000	.000	.000	.000	.00	.00	.00	.00	.00	.00	.00	.00	.00	
							m	n	a	b(1)	b(2)	c	y	z	

HYPERPEPSIA

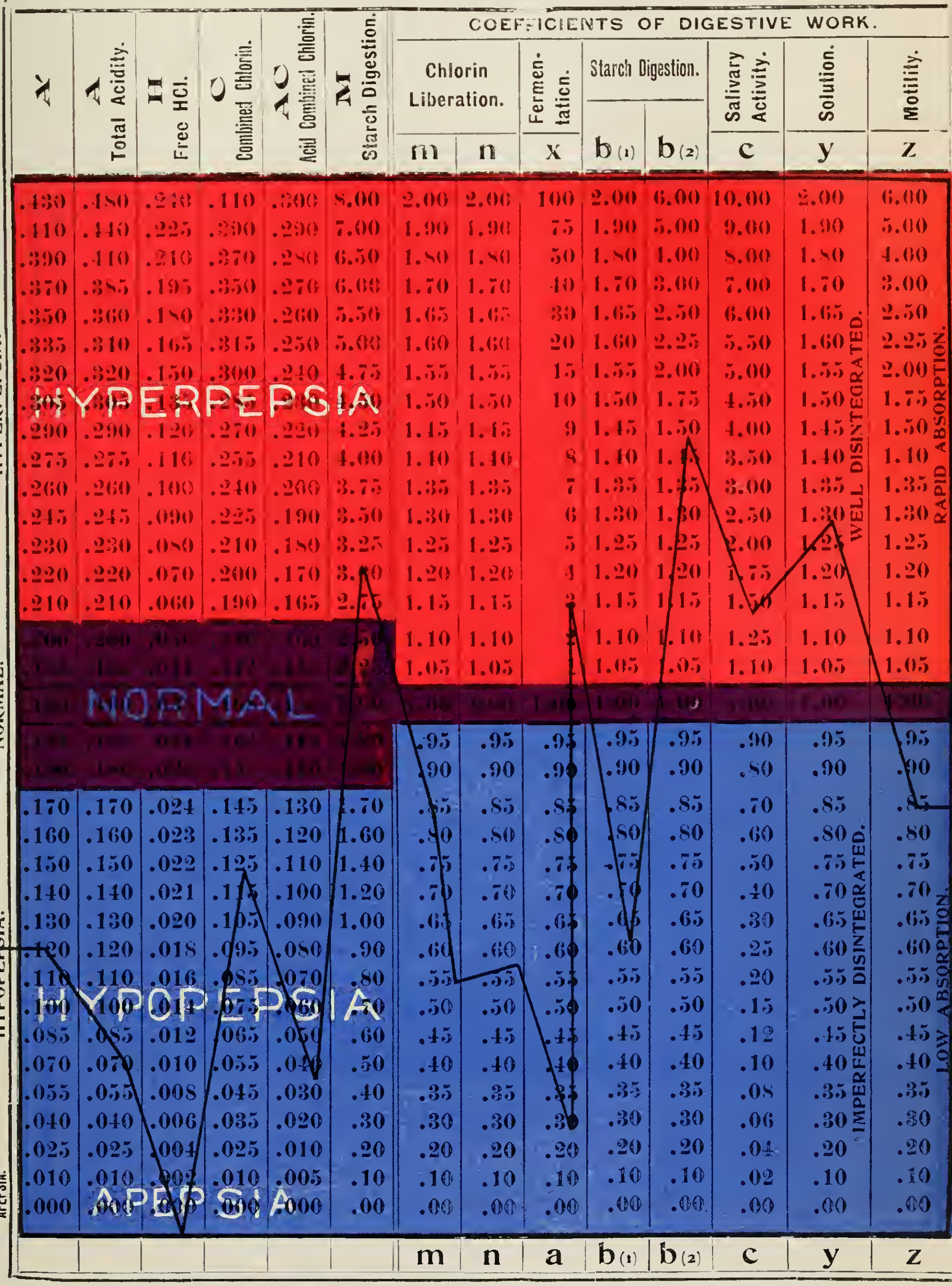
HYPOPEPSIA

APEPSIA

GRAPHIC REPRESENTATION

Of the Results of the Chemical Examination of Salivary and Gastric Digestion.

NO. 11599.



subject is required first to abstain from all food for ten or twelve hours; and he is then given to eat a bowl of Granose, a dry wheat product. He is not allowed any fluids at this test meal. After one hour the contents of the stomach are extracted and subjected to physical and chemical examination. The chemical examination reveals, to begin with, the amount of chlorine present in different forms, which determines the acidity of the stomach and so the power of proteid digestion. This analysis reveals three main types of digestive disorder,—hyperpepsia, hypopepsia, and apepsia. Speaking in a general way, hyperpepsia denotes an excessively acid stomach, hypopepsia a stomach in which there is not enough of acid for proper digestion, and apepsia a stomach in which there is almost no native power of proteid digestion. These types of stomachs are indicated in the charts by the different colored areas, the red denoting the hyper-acid stomach, so to speak, and the blue the sub-acid stomach.

The test for chlorine in its different combinations shows, in the first place, the total acid condition of the stomach, which is denoted in the chart by *A*. Taking a given quantity of stomach fluid, usually 100 cubic centimeters, it has been determined that the normal amount of acid ranges from .180 to .200 grams. This is indicated in the chart by the purple area, denoting that a stomach containing this proportion of acid is normal in its digestive power. Then the figures above and below the normal area denote the relative proportion of excess or lack of acidity. The column headed *H* denotes the amount of free hydrochloric acid which has been found in the quantity of stomach fluid examined. It is calculated that the normal amount in 100 cubic centimeters of stomach fluid ranges from .025 to .050; all quantities above this amount are excessive, those below are insufficient for proper digestion. The column headed *C* denotes the amount of combined chlorine; that headed *A′* indicates the amount of free hydrochloric acid and combined chlorine taken together. A′ represents the quantity of work, without reference to quality, which the stomach does.

Now, by referring to the two charts it can be seen that No. 8,938 possesses what may be called an acid stomach. Column A′ which denotes the working power of the stomach, shows that it is excessive, which means that the food which is eaten is not likely to be fully assimilated; it is disposed of too rapidly. On the other hand, No. 11,599 possesses a sub-acid stomach, where the proteid digestion is defective; the free hydrochloric acid is seen to be especially lacking. In prescribing a diet for these two individuals a physician would say that No. 8,938 should abstain from acids in every form, while No. 11,599 is much in need of acid that can be obtained in fruits. I happen to know as a matter of act that if No. 8,938 drinks a glass of lemonade it will cause distress, while No. 11,599 is greatly benefited by lemonade used very freely. The first subject cannot eat sour apples with impunity, while the second subject is very greatly benefited by their generous use. No. 8,938 likes foods rich in proteids, probably because they are easily digested; while No. 11,599 is not so fond of beans and similar foods containing a large proportion of albumen. If No. 8,938 drinks a glass of milk between meals he finds it difficult of digestion, doubtless because the excessive acidulous condition of the stomach causes coagulation of the casein before the digestive juices can act upon it in a proper way. No. 11.599 does not apparently experience inconvenience from a glass of milk at any time.

The analysis of stomach fluid reveals other digestive characteristics than those already discussed. It will be seen by an examination of the charts there is a column headed S in one case and M in the other in which is represented the capacity for starch digestion. This is determined by ascertaining the percentage of maltose, expressed as dextrin, found present in the stomach fluid. The normal amount in 100 cubic centimeters ranges from 1.80 to 3.00. (The charts do not quite agree here, due to the fact doubtless that the normal amount has been found to be different as a result of more extended analyses. As the analysis of No. 11,599 was made last, however, it is probable that it represents more correctly the normal amounts, which

would then range from 1.80 to 2.50 grams.) Quantities above or below these figures indicate a defect in digestive power. While No. 11,599 is sub-normal in proteid digestion, he is hyper-normal, if the term will be allowed, in starch digestion. No. 8,938 shows excess work here as in the case of proteid digestion.

As an outcome of these examinations it is possible to determine the working power of the stomach in various directions, and the results are indicated in the charts by coefficients of digestive work. It can be seen that No. 8,938 does excessive work in respect of the liberation of chlorine during the digestive processes, indicated by the tracing in the columns *m* and *n*. No. 11,599 is quite deficient in this regard. The coefficient of proteid digestion is *a*, and this power is shown to be normal in the acid but deficient in the hypopeptic stomach. The coefficient of fermentation is *x*, which is shown to exist in the case of No. 11,599 but not in the other instance. The coefficients of starch digestion are of two kinds: b_1, which denotes the relation of the perfectly digested starch or maltose found in the stomach fluid to the dextrin and soluble starch which is imperfectly digested or converted; and b_2, which has reference to the amount of maltose or perfectly digested starch to the amount found in normal digestion. No. 8,938 is sub-normal in the first sort of digestion, and hyper-normal in the second; and substantially the same condition is found in the other stomach. The power of salivary activity is represented by the coefficient *c*. This is determined in the experiment by requiring the subject to chew gum for a given length of time, the saliva secreted being collected and examined. The column headed *y* relates to the digestive activity of the stomach with reference to the power of disintegrating the food substances; it is determined by comparing the undissolved residue of the fluid with the total amount of stomach fluid obtained. In both stomachs there is less than the normal amount, which shows excessive activity in this respect. Finally the examination shows the rapidity with which the stomach fluid is disposed of. The coefficient *z* refers to this digestive capacity, and is obtained by a compari-

son of the amount of residual fluid found in the stomach at the end of the first hour of digestion after a test meal with the normal amount. It can be seen that in No. 8,938 the food is hastened too rapidly, while in No. 11,599 absorption does not proceed rapidly enough.

It must be apparent then that these differences in digestive capacity advise somewhat different practices with respect to the quantity and quality of foods eaten; but the most marked difference between the stomachs is that relating to the digestion of proteids, one individual needing to augment the natural supply of acid in order to promote the digestive process, while the other is embarrassed by the too bounteous gifts of nature.

CHAPTER VII.

EXPENSE OF DIETARIES.

§1. *Taste Versus Expense in the Choice of Foods.*—In an older day men lived to eat; the gratification of the palate was the *summum bonum* of life. But the times have changed; life is now seen to be more real and earnest and the table is not its goal. But yet there are those among us who, while holding to the higher and more spiritual ends of existence, still believe that food should be chosen with reference to its taste, to its aesthetic qualities, so to speak, rather than for its nutritive properties. "Eat what you like," these people say; "this business of seeing how you can get the greatest nutrition for the least amount of money is unworthy cultured beings." Such persons select their meats, their breads, and their wines primarily because they are agreeable to the palate. Among some, the choice of food upon this principle has developed into a fine art. As great pains are taken in planning a bill-of-fare as in painting a picture;—there must be as great harmony of gustatory sensations in the one as of visual sensations in the other. The question of value for money expended does not enter into the construction of a dietary at all with these neo-Epicureans.

Now, it seems to be a law of our being that what is indifferent, painful, or repugnant cannot exercise a beneficial influence upon us; that alone which is pleasureable seems to heighten the tide of life. It is probable, too, that of all manner of obnoxious things distasteful food is the worst; and so there is really a show of reason in the doctrine, eat what you like. But upon close examination it does not go very far; it assumes that there is incompatibility in deferring to the pocket-book and to the palate at the same time. The conviction seems to be deeply settled in many people's minds that what is nutritious is not

tasty; and what is palatable may or may not have any nutritive value, usually not. As a matter of fact, however, common sense would suggest that what is best for the organism in the long run affords the most agreeable gustatory sensations. The palate never would have survived in the crisis of evolution if it had not thus served the body faithfully. If in its pristine condition it selected foods which, while ministering to taste yet were of little account in meeting the needs of existence, the race would have disappeared in its infancy. Evolution, then, confirms what unprejudiced observation and personal experience will tell anyone,—that the most palatable foods fulfill the requirements of perfect nutrition most satisfactorily.

§2. *The Cost of a Dietary of Different Foods.*—But however the philosophy presented in the preceding section may be regarded by some, yet it will readily be granted by all that in student life, as it is found in our community, the question of securing nutrition at the least expense is a vital one. Considerably over one-half of our students feel the need of economizing in every direction during their university career, and it is probable that there is no place where wise economy would be more effectual than in the arrangement of the dietary. This may be accomplished, and I believe without doing violence in any way to the legitimate rights of the palate. There are appended tables showing that the requirements of a perfect bill of fare can be met with different foods at greatly varying expenditures. To illustrate: If one had twenty-five cents to expend for food, it would purchase for him almost no nutrition in oysters, for instance, but it would yield very large returns if spent for bread, or oatmeal, or cornmeal, as the following figures show:

Amounts of nutrients furnished for twenty-five cents in food materials at ordinary prices. (Atwater, op. cit., p. 28.)

FOOD MATERIALS AS PURCHASED.	Price per pound.	25 CENTS WILL PAY FOR:					Fuel value.
			Nutrients.				
		Total food materials.	Total.	Protein.	Fats.	Carbohydrates.	
	Cents.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Calories.
Beef, sirloin	10	2.50	.79	.38	.41	....	2,425
Beef, sirloin	15	1.67	.52	.25	.27	....	1,620
Beef, sirloin	20	1.25	.39	19	.20	....	1,215
Beef, sirloin	25	1.00	.31	.15	.16	....	970
Beef, round	8	3.13	.95	.59	.39	....	2,675
Beef, round	12	2.08	.63	.37	.26	....	1,780
Beef, round	16	1.56	.47	.28	.19	....	1,335
Beef, neck	4	6.25	1.85	.98	.87	....	5,500
Beef, neck	6	4.17	1.23	.65	.58	....	3,670
Beef, neck	8	3.13	.93	.49	.44	....	2,755
Mutton, leg	8	3.13	.96	.47	.49	....	2,925
Mutton, leg	14	1.79	.55	.27	.28	....	1,675
Mutton, leg	20	1.25	.38	.19	.19	....	1,170
Ham, smoked	10	2.50	1.23	.37	.86	....	4,340
Ham, smoked	16	1.56	.77	.23	.54	....	2,705
Salt pork	10	2.50	3.09	.02	2.07	....	8,775
Salt pork	14	1.79	1.50	.02	1.48	....	6,285
Salt pork	18	1.39	1.16	.01	1.15	....	4,880
Cod, fresh	6	4 17	.45	.44	.01	....	855
Cod, fresh	10	2.50	.27	.27	....	.. ....	510
Cod, dry salt	6	4.17	.68	.67	.01	....	1,315
Cod, dry salt	8	3.13	.51	.50	.01	....	985
Mackerel, salt	10	2.50	.74	.37	.47	....	2.275
Mackerel, salt	15	1.67	.49	.24	.25	....	1,520
Oysters, 25 cents a qt	12.5	2.00	.24	.13	.03	.08	520
Oysters, 35 cents a qt	17.5	1.43	.17	.09	.02	.06	370
Oysters, 50 cents a qt	25	1.00	.12	.06	.02	.04	260
Eggs, 15 cents per doz	8.8	2.84	.63	.34	.29	....	1,660
Eggs, 25 cents per doz	14.7	1.70	.37	.21	.17	....	1,115
Eggs, 35 cents per doz	20.6	1.21	.27	.15	.12	....	790

Amounts of nutrients furnished for twenty-five cents in food materials at ordinary prices.— Continued.

Food Materials as Purchased.	Price per pound.	25 Cents will Pay for:					Fuel value.
		Total food materials.	*Nutrients.* Total.	Protein.	Fats.	Carbohydrates.	
	Cents.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Calories.
Milk, 3 cents per qt..............	1.5	16.67	2.05	.60	.67	.78	5,420
Milk, 6 cents per qt..............	3	8.33	1.02	.30	.23	.39	2,705
Milk, 8 cents per qt.....	4	6.25	.77	.23	.25	.29	2,030
Cheese, whole milk..............	12	2.08	1.36	.59	.74	.03	4,305
Cheese, whole milk...	15	1.67	1.09	.47	.59	.03	3,455
Cheese, whole milk..............	18	1.39	.91	.39	.49	.03	2,875
Cheese, skim milk...............	6	4.17	2.25	1.60	.28	.37	4,860
Cheese, skim milk...............	8	3.13	1.69	1.20	.21	.28	3,645
Cheese, skim milk...............	10	2.50	1.35	.96	.17	.22	2,910
Butter..........................	15	1.67	1.45	.02	1.42	.01	6,035
Butter..........................	25	1.00	.86	.01	.85	....	3,615
Butter..........................	35	.71	.61	.01	.60	....	2,565
Sugar	5	5.00	4.89	....	....	4.89	9,100
Sugar	7	3.57	3.50	....	....	3.50	6,495
Wheat flour....	2	12.50	10.87	1.37	.14	9.36	20,565
Wheat flour.....................	2.5	10.00	8.70	1.10	.11	7.49	16,450
Wheat flour.....................	3	8.33	9.24	.91	.09	6.24	13,705
Wheat bread.	3	8.33	5.56	.73	.14	4.69	10,660
Wheat bread.....................	5	5.00	3.34	.44	.08	2.82	6,400
Wheat bread.....................	8	3.13	12.09	.28	.05	1.76	4,005
Corn meal.......................	2	12.50	10.45	1.15	.47	8.83	20,565
Corn meal.......................	3	8.33	6.97	.77	.32	5.88	13,705
Oatmeal.........................	3	8.33	7.51	1.22	.59	5.70	15,370
Oatmeal.........................	5	5.00	4.52	.74	.36	3.42	9,225
Rice	5	4.17	3.64	.31	.02	3.31	6,795
Rice	8	3.13	2.73	.23	.01	2.49	5,100
Beans	0.75	5.00	4.22	1.16	.10	2.96	8,075
Potatoes, 45 cents per bush	9.75	33.33	5.70	.60	.03	5.07	10,665
Potatoes, 60 cents per bush	1	25.00	4.27	.45	.02	3.80	8,000
Potatoes, 90 cents per bush	1.5	16.67	2.85	.30	.02	2.53	5,335

§3. *Local Expenses, With Practical Suggestions.*—The average expense for table board in our community, as reported by 326 students, is $2.74. Some students pay $4.00, a few pay $1.00, the majority come very near $2.50. This is about the figure reached in the experiments made at the Maine State Agricultural College.[1] If abundant nutrition were obtained for this amount, it would probably not be excessive; although it is much greater than is necessary if a person finds it desirable to economize rigidly. Atkinson[2] has calculated bills-of-fare which afford ample nutrition and give variety, but which do not exceed in cost $.96 a week. Atwater's dietary lists at exceedingly moderate prices have already been given.[3] At the Battle Creek Sanitarium there are in the neighborhood of one thousand helpers living very well on $.75 a week or less; and there is no body of people to be met anywhere who appear better nourished, or who manifest greater efficiency in body and mind. It is certainly not overstating the case to say that our students, regarded in the whole, could live very much better than they do for the amount which they expend; and many of them who deprive themselves of social advantages for pecuniary reasons might a great deal better economize in their food with profit to their pockets and their stomachs. Of course it is impossible in the majority of instances for a single person to inaugurate reform; but where a hundred men are banded together in a club, a little planning, a little intelligent study of the problems involved, such as they would expect to do if it were any other matter under the sun, would be of tremendous advantage to them. Perhaps the day may come some time when the man who essays to manage a club or boarding house will bear some credentials testamentary of his fitness for this business other than that he is a "hustler," or is in need of money, or can find nothing else to do.

If one were to suggest methods of economy, he would first attack the meat which is found in students' dietaries, for this

[1] Jordan, op. cit.
[2] Op. cit., pp. 175 et seq.
[3] Chap. III.

is the most costly of all articles of food, as Jordan[1] and many another experimenter have found.[2] It can be readily seen that to raise wheat and corn and then feed them to cattle must make the product more expensive than to use the grains in their original form for human food. The process of passing corn through cows and hogs before it reaches man involves time and labor and waste which the consumer of flesh must pay for. Paley[3] wrote as follows upon this subject some time ago:

"In England, notwithstanding the produce of the soil has been considerably increased by the enclosure of wastes, and the adoption, in many places, of a more successful husbandry, yet we do not observe a corresponding addition to the number of inhabitants, the reason of which appears to me to be the more general consumption of animal food amongst us. * * * If we measure the quantity of provision by the number of human bodies it will support in due health and vigor, this quantity, the extent and quality of the soil from which it is raised being given, will depend greatly upon the kind. For instance, a piece of ground capable of supplying animal food sufficient for the subsistence of ten persons, would sustain at least the double of that number with grain, roots, and milk."

Dr. Richardson, in "Modern Thought" for July, 1880, develops this thought in an interesting way. He says:

"We really ought to consider the question of utilizing, on a large scale, all vegetables which, in nutrient value, stand above animal products. We have also to learn, as a first truth, the truth that the oftener we go to the vegetable world for our food, the oftener we go to the first, and, therefore, to the cheapest source of supply. The commonly accepted notion that when we eat animal flesh we are eating food at its prime source cannot be too speedily dissipated, or too speedily replaced by the knowledge that there is no primitive form of food—albuminous, starchy, osseous—in the animal world itself, and that all the processes of catching an inferior animal, or of breeding it, rearing it, keeping it, dressing it, and selling it, mean no more nor less than entirely additional expenditure throughout for bringing into what we have been taught to consider an acceptable form of food the veritable food which the animal itself found, without any such preparation, in the vegetable world."

[1] Loc. cit.

[2] See, for instance, Atwater, op. cit., p. 23; also Smith, quoted by Kingsford, *The Perfect Way of Diet*, p. 103.

[3] *Principles of Moral and Political Philosophy.*

Dr. Lyon Playfair, the well known English scientist, prosecuted a series of official investigations for several years on the subject of military rations in England, France, Prussia, and Austria. He found that in order to obtain the right amount of albuminous matter it would be necessary to consume weekly:

	Price (about) s.	d.
147 ounces of butchers meat	6	1
or 93 ounces of cheese	3	0
or 341 ounces of ordinary white bread	2	8
or 175 ounces of oatmeal	1	4
or 127 ounces of dried peas	1	2

In order to obtain the necessary proportion of dynamic or caloric-forming substance, it would be necessary to consume weekly:

	Price (about) s.	d.
416 ounces of butcher's meat	17	4
or 224 ounces of cheese	7	0
or 298 ounces of ordinary bread	2	3
or 616 ounces of potatoes	2	9
or 221 ounces of dried peas	1	10
or 183 ounces of oatmeal	1	0

These figures, with others given on preceding pages, show conclusively that meat is not an economical food from which to obtain the energy required for either mental or physical labor.

Herbert Spencer, when considering some years ago the advisability of living more largely upon a vegetable diet,[1] complained that it was impossible to get the requisite amount of albumen without too much energy being expended in digestion. This objection is assuredly an important one. It has already been said that to overburden the system with innutritious, indigestible and largely waste materials results in a limitation of its efficiency; and when the albuminoids cannot be easily obtained in peas, beans, grains, and nuts the additional expense for meat in student dietaries is certainly justified. But I maintain what has already been urged, that right cooking and the freer use of pulse and nut foods and grains, as cereals and breads, rich in

[1] *Education*, p. 240.

albumen will give us this element in as digestible and concentrated form as can be obtained in meat, and this will enable the student to economize considerably in his dietary.

Another direction in which economy can be secured is in the total abolition of pies, cakes, pickles, and the like. They really serve no useful purpose in the dietary; nutritious foods will minister to the appetite just as fully and will in addition recompense the eater for his financial outlay.

CHAPTER VIII.

FRESH AIR, EXERCISE AND REST IN THE PRODUCTION AND EXPENDITURE OF CEREBRAL ENERGY.

§1. *Function of Oxygen in the Organism.*—Many people seem to think that albumen, fat, and carbohydrates are sufficient in themselves to supply the organism with energy; if you eat enough, they say, you will be vigorous enough in mind and body. But a little reflection will teach one that fat and carbohydrates as such are only force *in potentia,* so to speak. They are absolutely powerless in the system until they are oxydized, so that an adequate supply of oxygen is as essential to proper nutrition, in the broad sense, as a liberal quantity of carbohydrates and other substances. An organism deprived of a due allowance of oxygen becomes lethargic; and if it be altogether cut off, entire absence of action supervenes, a fact with which everyone is of course familiar.

Now, observation and experiment have indicated somewhere near the amount of oxygen which the human body requires for greatest efficiency, and this must be secured by a constant apportionment of air containing the "life giving element" in a certain uniform proportion. In determining this proportion the ratio of CO_2 to the other constituents of an atmosphere is usually taken as an index of the purity of that atmosphere, since this gas is generally found in the presence of other gases which vitiate the air. It has been calculated that more than 4 parts of carbonic acid gas in 10,000 parts of air renders the latter incapable of furnishing oxygen to the system in the required quantities.[1] This estimate can be only relatively true, however, since organisms differ respecting the amount of oxygen which they need to support mental and bodily activities. A

[1] For the results of investigations relating to this subject, see Burnham, Pedagogical Seminary, June, 1892, p. 23, et seq.

high-strung individual, as we say—one who is intense in thought and quick and vigorous in physical movements—must needs generate more vital force than a person of an opposite temperament. Again, one possessing a relatively large inhalant system can thrive in an atmosphere where a small-lunged unfortunate would be able to do little more than keep body and soul together.

But for the average individual it is essential in order that he may obtain the necessary quota of oxygen that there should be furnished him about 30 cubic feet of air per minute; and this with the ordinary methods of ventilation will necessitate about 225 cubic feet of space[1] being set apart for his sole tenantage. These figures can only be suggestive, since the volume of space demanded depends upon the rapidity with which the air changes and upon its richness in oxygen. But taking these estimates as of general trustworthiness, we find that the majority of our students are fairly well circumstanced in respect of elbow room in their living quarters. In our questionnaire we asked for the size of their apartments, with the number of persons they contained, and the following table presents the results:

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[1]Martin (*Human Physiology*, p. 377) says that an individual should be supplied with 800 cubic feet of space; but it is probable that this is not at all essential in properly ventilated apartments. Burnham, *op. cit.*, summarizes the results of investigations upon this subject as follows: "According to M. de Chaumont, at the International Congress of Education at Brussels in 1880, Belgium prescribed one square meter of floor-space and 4.5 cubic meters of air-space to each scholar; but the Educational League of Belgium, in the plans of its model schools, proposed 1.67 sq. m. of floor-space and 9.6 cu. m. of air-space to each pupil. In Holland the average per head was 4.54 cu. m. In England, in the Board Schools, about 1 sq. m. of floor-space and from 3.65 to 4.25 cu. m. of air-space were allowed. Bavaria prescribed 3.9 cu. m. for scholars of eight years, and 5.6 cu. m. for those of twelve years. In Sweden, in the primary schools 1.52 sq. m. and 5.35 to 7.55 cu. m.; in the higher schools 2.17 sq. m. and 7.69 to 9.98 cu. m. per head were allowed. In Switzerland the regulations vary in different cities. In Berne a subcommittee of the Police Directors reported two or three years ago in favor of 4 cu. m. per pupil under ten, 5.5 cu. m. for pupils over ten; in all cases 1 sq. m. of floor-space. In some schools as much as 6.50 cu. m. of air-space per child is required. In Austria 0.6 sq. m. and 3.8 to 4.5 cu. m. are required. In the country schools in Prussia a floor-area for each pupil of at least 0.64 to 0.74 sq. m. and a height of 3.20 m.—therefore at least 2 to 2.37 cu. m. of air space—are provided. In the higher schools from 3.9 to 5.2 cu. m. are required. In Wurtemberg from 3 to 5 cu. m., in Hesse and Baden 3 cu. m. are prescribed for each pupil."

No. in room.	Smallest.	Largest.
1	9½ x 9 x 8	16 x 14 x 8
2	12 x 15 x 9	24 x 12 x 8
3	10 x 12 x 8	12 x 16 x 8

It is apparent at a glance that so far as breathing space alone is concerned our students are on the whole well off. But the method of heating determines in largest degree the oxygen value of the atmosphere of any room which is much used. One heated by steam, with no provision for the entrance of fresh or the exit of expired air, is quite certain to be improperly oxygenated, be it ever so spacious; and people living therein are likely to experience sooner or later a decrease in their energies. About one-third of our students reported that their rooms were heated by steam, over one-half were favored with hot air, while fifty-four were kept warm in the old-fashioned way, by coal and wood stoves. It is probable that the most satisfactory method of heating, regarded from the point of view from which we are considering the subject, is by hot air, where the wholesomeness of the atmosphere is more easily secured. On entering a house in winter it is not difficult to detect whether it is heated in this or in some less hygienic manner. It may be added here by way of exhortation that students occupying apartments heated by steam or by stoves must give especial attention to ventilation. And this is as necessary at night as during waking hours; for it seems, as Richards says,[1] that during sleep the organism stores up oxygen which is to be utilized in generating force for the activities of the following day.

The effect of inadequate ventilation is readily apparent in lessened vigor of mind and body, and there can be no doubt that mental acumen and endurance in some cases, and lethargy and dullness in others, find their explanation in the quality of air habitually inspired. It may be remarked in passing that this subject needs attention from university authorities as well as from students themselves. A class-room filled full of seekers

[1] The Northwestern Monthly, Vol. VIII, July, '97.

after knowledge, and which retains from day to day the respiratory contributions of its occupants, is, to say the least, a poor mount on which to entertain the Muses. Libraries in which the atmosphere is rarely changed furnish occasion for idle and even stupid gazing at books; one cannot drink deeply at the Pierian spring in such a place. Morrison[1] has well said that in a comfortable atmosphere of proper temperature and purity as much labor can be accomplished in one hour as can be accomplished in six hours in an atmosphere rendered impure by respiration.

§ 2. *Exercise.*—Doubtless every one is familiar with the most important effects of physical exercise upon the somatic functions. Hygiene has taught us these many years that muscular activity quickens circulation, stimulates the organs of elimination, arouses lethargic cells in all parts of the body, creates a need for oxygen which results in increased respiration; and, in short, produces a general feeling of euphoria, of well-being, which must be of distinct advantage to the organism from whatever point of view it is regarded. That which heightens the tide of life as a whole must be considered as fostering more vigorous and efficient mentation; so that if exercise produced directly only physiological effects in the organism, it would still be of inestimable benefit to the mind. But there are other ways in which it is of marked advantage to the mental life. For one thing, it relieves muscular tensions which sap the vitality of the physical medium of mind, a matter which will be discussed at length later.[2] The point which must receive special attention here relates to the value of exercise in promoting metabolism in the cerebral motor areas, and hence in augmenting the total energy-producing capacities of the brain. According to a now prevalent view of which Flechsig[3] is the most illustrious exponent, energy generated in one nerve cen-

[1] *The Ventilation and Warming of School Buildings.*

[2] Chap. X.

[3] See *Gehirn und Seele.* See also Curtis: Inhibition, Pedagogical Seminary, Vol. VI, No. 1; Burk, *op. cit.*, and Newsholme, *School hygiene*, Chap. XII.

ter may in a well organized brain be utilized in a different one; thus I may be producing a large amount of force in the motor areas of my brain but be employing it in the reflective, the thought regions. If I exercise any certain parts of the cerebrum more than others, energy tends to flow into them and out of the unused areas. Cerebral energy may not inappropriately be likened to water in respect of its tendency to seek a level; if it be drawn out in one quarter, it will rush in from others to preserve the equipoise. This theory, which is in harmony with our knowledge of the structure of the cerebrum as an instrument for the production and transmission of energy, is also corroborated by the familiar experience of inhibition in daily life. Every one must have observed that when he thinks vigorously, the degree and force of physical action is lessened; and, on the other hand, when the muscles are most active the mind is relatively inert. Now, it seems to be a rational supposition that mental activity inhibits physical activity, because it draws away from the motor centers energy required for muscular action. When the mathematical part of the brain, for instance, is intensely active, we may conceive that energy from other localities sets in toward this as a focus, and so activity in other regions is lessened; all is expended upon the particular undertaking in hand.

Now, if this theory be valid, an inference may be drawn from it of vital significance in regard to the value of exercise for brain workers. If the cerebral motor areas be maintained in a vigorous condition; if the metabolism of the cells be kept at its best, that is to say, then the surplus energy generated here may be utilized in intellectual labor. On the other hand, one who does not use his muscles, who does not stimulute the motor cells, fails to make use of great laboratories for the production of vital force. A student who, desiring to accomplish the most in his studies, denies himself all physical exercise must, according to our theory, be a loser in the end. And in more ways than one. He not only fails to keep in their prime all the energy-generating powers of the brain, but he really

breaks up the unity between intellectual and motor activities which seems to be essential for the best mental health and balance. A certain amount of motor activity is without doubt necessary for the stability and integrity of mind, and this is becoming more apparent every day as the pathological aspects of psychology are being more carefully examined.[1] On account of this close relationship between mental and motor activity, it is probable that at no time in life can one divorce them entirely with safety to either mind or body.

The question respecting the amount of exercise which is most suitable for students is a vital one. In the present state of our knowledge it is impossible to give a definite answer to this; about all that can be said now is that each person must test the matter for himself, taking for his guide the principle that his physical activities should serve the purpose of keeping the organism in proper repair and furnishing energy to sustain mental effort. In so far as it fails to do this, it must be regarded as of little value, and it may be distinctly detrimental. If one's experience in the gymnasium or out of doors lessens the capacity for sustained mental effort, it shows that it is either excessive or not adapted to the needs of the individual. If one will become conscious of the matter for a time, he can doubtless make a rule fairly well adapted to his peculiar necessities.

While it is probable that many students in our university do not have exercise enough, yet it is certain that some have too much for the best intellectual work. I have been able to observe with some care for one year the mental processes of one of our athletes. During the fall he was under heavy training, and throughout the whole of that period he was less keen, vigorous, and sustained than usual in all of his intellectual labor. He could not reason well, was not quick in apprehending a point, was not ready in retaining or recalling what had apparently been mastered from day to day. Two or three weeks after the ath-

[1] Cf. Seguin: *The Treatment of Idiocy by the Physiological Method;* cf. also Wey, quoted by Hancock, *A Study of Motor Ability*, Ped. Sem., Vol. III, p. 24; Burk, *op. cit*; Oppenheim, *op. cit.*, chap. V.

letic season had closed his mind brightened up considerably, showing improvement in every direction. I conversed with him frequently regarding his mental performances, and he was conscious himself that undue physical exertion occurred at the expense of intellectual acumen and vigor.

It may appear to some who read the above paragraph that it conflicts with the popular belief that athletes make the best scholars. I am inclined to think that an athletic student who does not go beyond bounds in his training for contests is likely to be superior in his mental tasks, since he has more energy which can be employed in this direction if he will only reserve it in right measure for that purpose. It is easy to see then why a good athlete should attain high rank in scholarship in the long run, and at the same time do poor work while under training. When he does give himself up fully to his studies, he can accomplish more than the general run of folks and so keeps up his average; but if he continues in severe training throughout the whole year, I think it is altogether unlikely that he will attain fame in things of the mind.

Our students vary a good deal in the amount of exercise which they take. Twenty say they spend one hour a day in the gymnasium, forty-eight spend two hours, and thirty-four spend three hours. In many of the answers it was impossible to tell whether exercise was taken every day or only on special days in the week. A majority of our students reporting spend more time out of doors than in the gymnasium. One hundred and thirty-three spend about an hour a day out of doors, eighty-three spend two hours, and forty-two are in the open air three hours a day. If one should hazard an opinion upon the practices of our students, he might say that those who take exercise systematically have probably on the average enough to meet their needs. One hour a day of quite vigorous exercise out of doors or in the gymnasium will probably, for the majority of individuals, serve to stimulate beneficially all the organs of the body, to eliminate waste materials, and to keep the motor centers in a healthy, active condition.[1]

[1] cf., for instance, Newsholme, *loc. cit.*

The particular form of exercise best suited to head workers is a very important matter. Regarded from our point of view, that kind of physical activity will be most efficient which keeps the cerebral motor areas in best repair, and which involves the least dissipation of vital forces. Now, it seems to be a principle of our human nature that what we like to do is in general better for us than the things we hate. Pleasurable activities create less wear and tear[1] than those which are distasteful, an arrangement we should infer from the principles of evolution, even if we had no confirmatory experience with it in our own lives. Disagreeable tasks lie along the lines of greatest resistance for the organism, so a relatively larger amount of energy must be expended in overcoming them; while on the other hand, what is agreeable opens up ways of easy progress, and makes comparatively little demands upon our powers. This doctrine is of vital consequence in relation to our physical exercise. Games and plays and gymnastics which are pleasurable will accomplish the purpose of recreation better than those which are indifferent or boresome. A game which will enlist our lively interest will do much more for us than formal drill which we have to coerce ourselves through. In other words, play, in the best sense of the term, whether in the gymnasium or out of doors, constitutes by all odds the most efficient method of exercise;[2] it usually involves the various organs of the body and utilizes highly co-ordinated and complex activities, so that all parts of the motor mechanism of the brain are brought into action. "Man is wholly man only when he plays," Schiller says. On the other hand, formal drill ofttimes makes use of only a few movements and so stimulates but small portions of the cerebral motor areas.

Again, so far as possible the will should be released in physical exercise. This is accomplished more largely in play than in drill which one dislikes; things which we hate we have to will

[1] cf. Johnson: *Education in plays and games;* Ped. Sem., Vol. 3, pp. 98 and 99.

[2] From the earliest times men have appreciated the transcendent value of play in the development of childhood and youth. See, for instance, Plato, *Laws,* I, 643 and Rep. VII, 537; Aristotle, Bk. VII, 17; Froebel, *Education of Man,* § 30; Locke in Quick's *Locke on Education,* p. 55, 76.

to overcome, while those activities which draw us spontaneously do not require for their execution an act of volition. Observe a boy at play and at work. The play may really be harder in the sense that more work is done and more difficult movements are performed, but yet his will is not exerting itself against obstacles and so he is really less fatigued over the heavier than the lighter task. And so it is with all of us; we tire much more readily in performing tasks in which we have no interest. Economy then demands that a student's physical exercises be genuinely pleasurable; that he go to them without having to drive himself. Recreation will then accomplish the purpose for which it is taken, rather than become an additional burden to an already overtaxed will.[1]

A word may be said before leaving this subject upon specific sorts of exercise. Dancing is a very common form in our community; one hundred and sixty-seven of our students reported that they danced, while one hundred and forty-eight did not. The frequency with which dancing occurs differs much with different students; many of the young women in Ladies' Hall dance every night after the evening meal; others dance once a week or once in three weeks; while a few dance once a semester. The amount of dancing at any one time is, again, quite varied. In Ladies' Hall it lasts for an hour in the evening. Two students reported to have danced frequently until 5 o'clock in the morning; the majority of the others, however, ceased their pleasures at 11 or 12 o'clock at night. It is not necessary here to present arguments in favor of dancing as a beneficial form of exercise; from our point of view it answers well all the requirements, especially when it is taken under conditions of good ventilation and proper temperature. But too emphatic condemnation can-

[1] cf. the following: O'Shea, Physical Culture in the Public Schools: Atlantic Monthly, Feb., 1895; Groos: *Die Spiele der Menschen*, especially *Zweite Abtheilung*, pp. 467–503 and 516–526; Hughes: Educational Value of Play, and The Recent Play Movement in Germany; Ed. Rev., Vol. XIII, pp. 327 et seq; G. E. Johnson; op. cit., pp. 97 et seq.; Earl of Meath: Public Playgrounds for Children; 19th Cent. Vol. XXXIV, pp. 267 et seq.; Gulick: Psychological, Pedagogical, and Religious Aspects of Group Games; Ped. Sem., Vol. XI, No. 2; and Some Psychical Aspects of Muscular Exercises, Pop. Sci. Mo., Vol. 53, pp. 793–805.

not be urged upon dancing until 12 o'clock at night once a week or once in two weeks or at longer or shorter intervals. This must be extreme for the average individual; and, like all kinds of excess, it must result in a positive detriment to the organism. While we have little data other than the testimony of experience for this statement, yet I think most people will agree that dancing for four hours produces fatigue, and that the individual is rather the worse for his recreation. If dancing be practiced as a form of business or of dissipation, that is one thing; if it is indulged in for recreation and recuperation, that is an altogether different thing. In order that recreation re-create it must refresh and not overtax; it must leave the individual with more of potency than he had when he started in, which cannot be the case when one dances four or five hours continuously. If we could only have dancing more frequently and for shorter periods, say twice a week lasting in no case beyond two hours, I believe it would be a valuable form of recreation; but it cannot be so considered as it is now practiced by many in our midst.

Brain workers will probably be benefited more by activities requiring the greater use of the fundamental than of the peripheral muscles. Gymnastics and games then should not require too exact and delicate co-ordinations, since it would seem that student life really demands enough of this sort of thing in the prosecution of studies. The cerebral areas controlling the peripheral muscles are doubtless involved in thinking, and it is desirable that our recreation should relieve these areas from active exercise while calling others into play. Again, it seems to me especially desirable that our amusements should engage the muscles principally rather than the mind. Cards, checkers, authors, and the like must be poorly suited to the needs of those who use their heads constantly in their regular employments. Whist is a study; it probably dissipates as much energy as algebra, and utilizes somewhat similar parts of the brain. A student's life economically planned would aim to expend in study all of the energies which should be devoted to intellectual activities, while recreation would involve motor activities almost wholly. Billiards, for example, must be regarded as a very su-

perior sort of recreation for a student, compared with euchre. Bowling is doubtless better still; and in short all pastimes in the gymnasium or out of doors that make the motor element prominent, are to be commended above those which are principally intellectual.

§3. *Sleep.*—In every living thing so far as we know periods of repose alternate with periods of activity. There is a kind of rhythm of action and of rest. Activity involves waste of living substance and cessation of action is essential that recuperation may take place. This rhythm is especially marked in human life. We have a long stretch, say sixteen hours, of waking life, during which mind and body are active and energy is dissipated; then there supervenes a season of quiet, when worn out tissue is repaired and the organism is brought back again to the normal condition. This period of rest seems to be even more important than nutrition for the preservation of life; for experiments have been made upon dogs showing that death followed more quickly from lack of sleep than from lack of food.[1]

Hodges' studies[2] demonstrating that in the case of animals cerebral cells were depleted of their contents after a day's activities and restored during the quiescent period of the night are suggestive respecting what in all probability takes place in principle in the human brain. Waking life robs brain cells of their substance; then during sleep, when the mind is in repose, the cells regain the energy which is essential for the sustenance of activity. If a man be denied sleep so that the drain upon nerve cells continues beyond a certain point, he will, of course, be thrown into a condition of fatigue, when intellect and emotions must suffer. It is then of vital consequence in student life that periods of activity and rest be so alternated as to keep the nervous organism in the best possible repair.

Now, it has not been determined by exact experiment, so far as I know, just how much sleep an individual needs. In all probability this differs with different people. There have been great historical personages, for instance, who have been able

[1] I have lost my authority for this statement, but I remember clearly the experiments and the outcome.

[2] Loc. cit.

while guiding the destinies of nations to survive on a very limited amount of sleep. Every one knows of Napoleon's capacity in this direction. On the other hand, Gladstone is said to have required seven hours' sleep quite regularly throughout his public life. In our own country there is a president of a great university who is reported to get along with at most four hours of sleep, and on occasions he is able to do well on two hours. But for the majority of individuals it is probable that somewhere near eight hours is essential.[1] Cowles,[2] Beard,[3] Mills,[4] and other writers upon nervous exhaustion are quite insistent upon this amount for all people; and while it may certainly be impossible for one individual to survive on what another will thrive on, yet it is probable that a third of the day spent in sleep could not but be of advantage to every person and in no case could it be a detriment.

The majority of our students give the required number of hours to sleep. Two hundred and thirteen reported that they devoted eight hours to this purpose; fifty-eight spend seven hours; thirty-four, nine hours; one, ten hours; four, six hours; while only two spend five hours. If their sleep be sound then our students should on the whole be well provided for in this respect. But in many cases people feel they are complying with all the requirements if they simply lie in bed. However, in order that sleep be fully reparative it ought to be peaceful and dreamless; otherwise the cerebral areas concerned in conscious mental life are active and energy is being dissipated. That one may secure this perfect rest his sleeping environment must be quite free from noise. Noise has a peculiar effect upon one asleep; even the slightest auditory stimulus seems to produce a waking reaction. It appears that there is in the human soul a sort of memory of earlier racial experiences where noise was a most significant affair; an animal that could not awaken instantly upon sounds of howling or cracking or crunching or breathing

[1] cf. Kotelmann, *School Hygiene*, pp. 187 and 225–231.

[2] *op. cit.*

[3] *op. cit.*

[4] Mental Over-work and Premature Disease Among Public Men. Smithsonian Inst., Lower Lectures, No. IX.

in his vicinity would have little chance of escaping from enemies lurking everywhere. And now, although man is quite safe in an environment of any amount of racket, yet he has not fully outgrown this old racial tendency to awareness in the presence of noise. It is instructive in this connection to observe a little child who in the earliest weeks trembles with fright at a loud noise, and cannot sleep except in an atmosphere of quiet.

The effect of noise upon a sleeping subject has been studied by Lombard and others,[1] and the results are conclusive in showing that even a slight disturbance causes a decrease in peripheral blood supply, indicating that the blood is flowing in increasing quantities toward the brain which tends to return to the waking state. The charts which follow show this phenomenon.

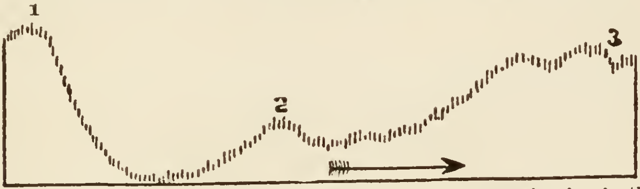

Fig. 11.—Plethysmographic record from the arm of a person sleeping in the laboratory. A fall in the curve indicates a decrease in the volume of the arm. The curve is to be read in the direction of the arrow. 1, the night watchman entering the laboratory; 2, the watchman spoke; 3, watchman went out. These changes occurred without waking the subject. (Donaldson, *op. cit.*, p. 289.)

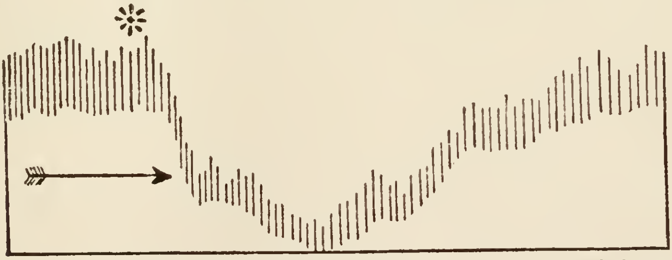

Fig. 12.—Record similar to that above. Change in the volume of the arm of sleeping subject, caused by the sound of a music box which was started at *. (Donaldson, *loc. cit.*)

The importance then of quiet while one is asleep cannot be too greatly emphasized. There should be a "rest" law in every house where students room, enacting that after a certain reasonable hour absolute quiet shall prevail. Certain it is, at any rate,

[1] See for instance, Angell and Thompson, *op. cit.*, for a summary of results of investigations.

that one whose sleep is not undisturbed will manifest the outcome in a lessened amount of vigor which may be utilized in intellectual work.

Some of our students preparing for examinations deprive themselves of sleep altogether for three or four nights. That this is a serious mistake hardly needs argument, it seems to me. It is probably not only a waste of energy in the long run, but really defeats the purpose for which the individual remains awake; for when the mind has been driven twenty-four hours without relaxation, it is not in a condition to do vigorous thinking; and if the strain be kept up throughout an entire examination week, the intellect must suffer in all its operations,—perception, memory, reason, and the rest. Some experiments have been made by Patrick[1] respecting the effect of prolonged absence of sleep upon muscular and intellectual capabilities, and these should be of interest to those students who study all night preparatory to an examination. The charts which follow indicate the increasing uncertainty in and diminution of various mental and physical powers as the period of constant waking life lengthens.

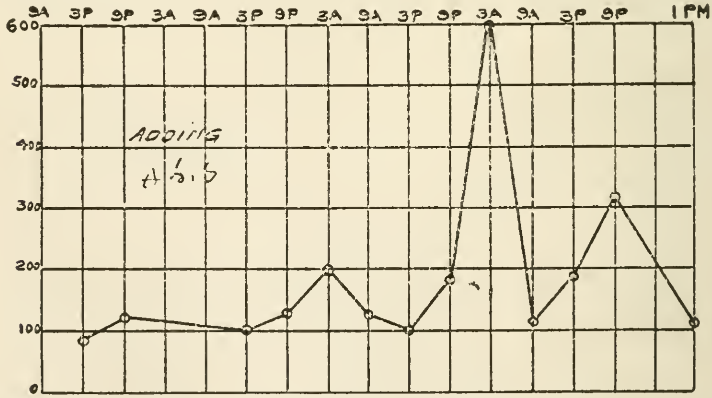

Fig. 13.—The ordinates show the number of seconds required to add a given number of figures. The abscissæ show the progress of the hours during the waking period. The last interval, however, representing the period of sleep following. (Patrick.)

[1] At the University of Iowa. See Studies from the Psychological Laboratory of the University of Iowa, Vol. I.

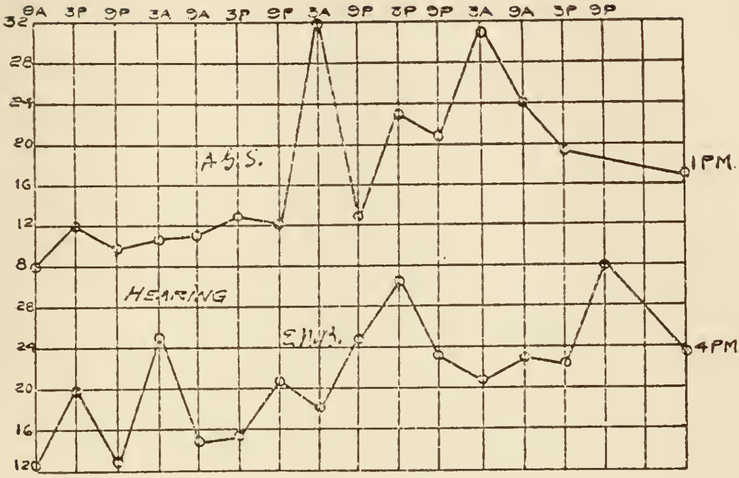

Fig. 14.—The ordinates show the relative intensities of sound required for discrimination. The abscissæ show the progress of the hour as explained above (Patrick.)

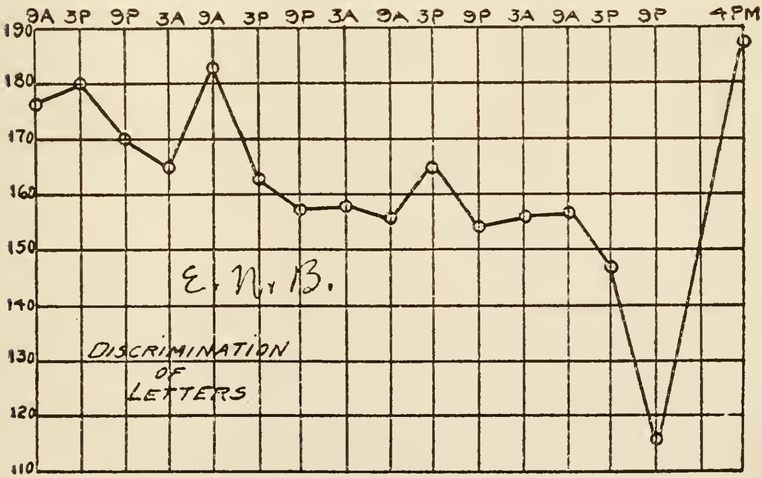

Fig. 15.—The ordinates show the number of letters named in one minute. The abscissæ show the progress of the hours as explained above. (Patrick.)

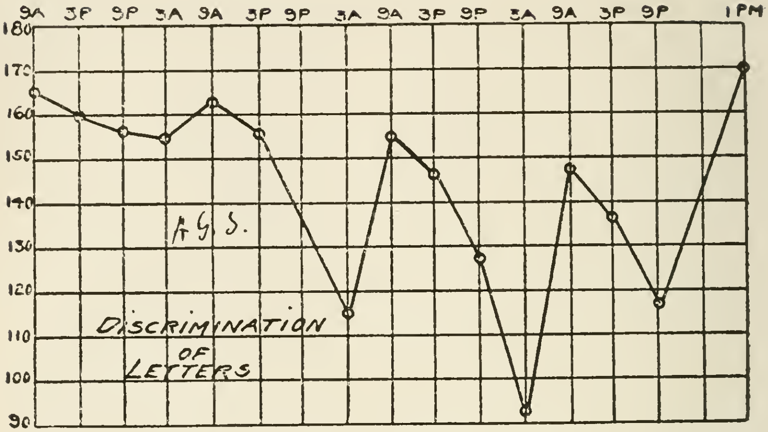

Fig. 16.—The ordinates show the number of letters named in one minute. The abscissae show the progress of the hours as explained above. (Patrick.)

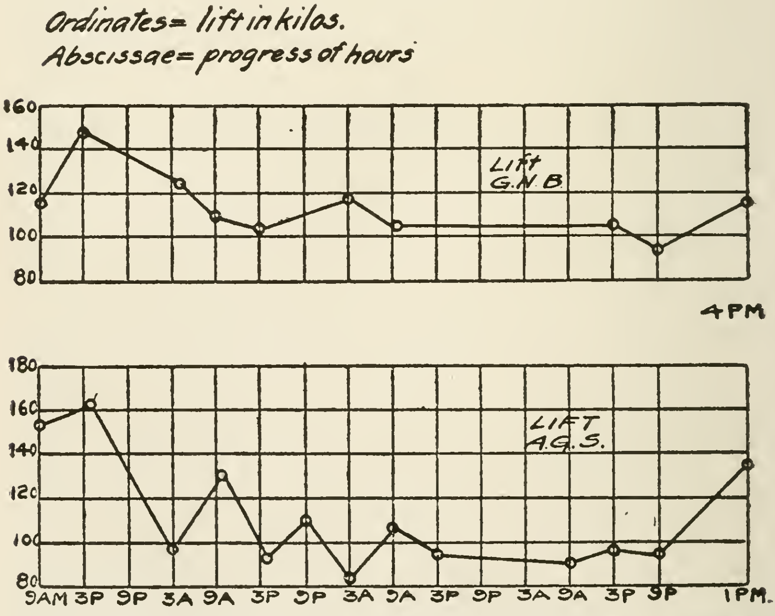

Fig. 15.—The ordinates show the strength of lift in kilograms. The abscissae show the progress of the hours as explained above. (Patrick.)

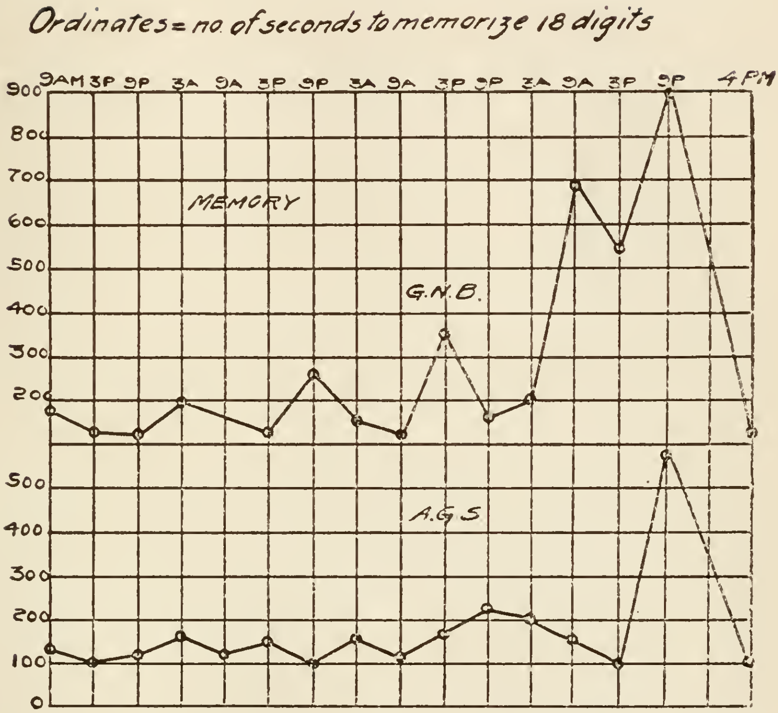

Fig. 16.—The ordinates show the number of seconds required to commit to memory 18 digits. The abscissae show the progress of the hours as explained above. (Patrick.)

It is probable, to add a last word, that a student who studies hard for say eight or ten hours has accomplished all that can be done with profit or with safety without a long period of sound sleep. Memory and reason will be more faithful and accurate the following day if the mind be thus refreshed than if it be driven on beyond the point of normal fatigue. And then when exhaustion is reached it requires such a relatively long time for recovery.[1] In normal fatigue a night's rest should bring complete restoration; but there is a point beyond this where the cell seems to lose the power of ready recuperation and it takes the spendthrift a long time to get back to himself, so to speak.

[1] See Hodge, *op. cit.*

CHAPTER IX.

THE CONSERVATION OF ENERGY.

§1. *Wasteful Muscular Tensions.*—It is recognized in mechanics that a large part of the energy expended in the working of a machine is wasted; a relatively small amount, say 25%, in the best machines is devoted to accomplishing the purposes for which the machine exists. The more perfectly a machine can be constructed so as to save this fruitless expenditure of force the more efficient it becomes, of course; and so it is of vital consequence that friction and other avenues of waste be blocked up as fully as possible. Now the human organism is a sort of machine; it has work to accomplish and a given quota of energy which may be drawn upon for this purpose. It is a truism that the greater the amount wasted the less can be expended in profitable production. But if one should maintain that this body of ours has been so carefully fashioned that there can be no loss of vital force, that all parts run together so smoothly and co-ordinate so perfectly that every item of expense is in lieu of value received, he would doubtless have a show of reason on his side. It would certainly be a fortunate arrangement if this most intricate of all mechanisms could run of itself without superintending and with no loss or unnecessary outlay of vital force; but I think we shall see that with the majority of us there are frictions which can be at least reduced by a little deliberate planning.

The greatest source of waste of neural energy is found in muscular tensions which are not at all essential to the accomplishment of the piece of work in hand. This is seen to be true in view of a simple physiological law,—that the exercise of a muscle involves stimulation from nerve centers. This stimulation implies a drain upon nerve cells,—an expenditure of energy, that is to say. When any task, as writing, is to be un-

dertaken, then economy demands that no muscles be active except such as contribute to the accomplishment of the work. But suppose that the hand not employed is clinched, the lips are compressed, deep furrows crease the forehead, and the fingers controlling the writing are unduly tense,—in such a case a large amount of effort is proving fruitless. The unnecessary constraints of muscles are simply draining the organism of energy that should be conserved and expended in profitable directions.

Now, there are certain practices in student life, as in the lives of people in general, which entail waste of vital forces and which can be modified without inducing too great self-consciousness. In the first place mental tension readily begets muscular tension. When the mind is perplexed; when it discerns obstacles ahead that seem insuperable; when conscience is incessantly active censuring one for past deeds and exhorting him to be especially careful in the future; when life seems full of cares that demand unceasing attention,—such a condition of mind produces constraints of muscles which sap the organism of its vitalities. When the attention is centered upon threatening difficulties the body unconsciously takes on an attitude of defense, as it were; or, to be more precise, the organism seeks to adapt itself to a mental situation and when we are troubled in mind our muscles get ready to annihilate the causer of our trouble, or to remove us therefrom.[1] One may see on our campus every day students with set faces, so to speak; there are deep lines between the eyes, there is a strain about the mouth, and the entire body shows rigidity and tension. When you talk with such students you can observe these abnormal "nerve-signs" in all the sensitive muscles of face, hands, and body generally. Such people are what might not inappropriately be called exhaustives; they are all the time drawing upon their bank deposits too heavily. Outlay commonly exceeds income, or at least there is no large balance on the credit side of the account. These are the over-conscientious individuals; they can never do anything without

[1] Cf. Angell and Thompson, Psychological Review, Jan., 1899, p. 69. See also Darwin: *Expression of the Emotions in Man and Animals* for a discussion of the general principle involved. Baldwin: *Mental Development, Methods and Processes,* Chap. VIII, treats of the subject in a readable way.

worrying about it before and afterwards; they are troubled lest they have not done or will not do just the right thing. They belong to what Ribot would call the egoistic-introspective type; they cannot get away from themselves, and hence are constrained and tense in most of their activities. It seems to be a law of our human nature that turning the mind upon self throws the machinery out of gear. Too much reviewing of conscience; too much hunting after one's faults ends in conscience being a very ineffective guide in life. Its mandates cannot be carried into effect by a weakened organism.

So much has been said in recent years about "Americanitis" that it may just be mentioned in this connection. It is maintained that our American people do not know how to rest; which means, I think, that they make a great deal more fuss about doing a thing than is necessary. Their actions are greatly in excess of that which the occasion demands. When they do things that should employ the hands only, they use the whole body; they scowl and grit their teeth, and in other ways drain off their forces. Dr. Clouston, the eminent Scotch authority upon nervous diseases, visited our country some time ago and is reported by James[1] to have said: "You Americans wear too much expression upon your faces. You are living like an army with all its reserves engaged in action. The duller countenances of the British population betoken a better scheme of life. They suggest stores of reserved nervous force to fall back upon, if any occasion should arise that requires it. This excitability, this presence at all times of power not used, I regard as the greatest safeguard of our English people. The other thing in you gives me a sense of insecurity, and you ought somehow to tone yourselves down. You really do carry too much expression, you take too intensely the trivial moments of life."

It is a vitally important matter in student life to acquire the habit of adjusting effort to the task to be accomplished. When great tasks are to be performed our forces must all be summoned to the fore; but it is certainly bad economy to expend as much

[1] Scribner's Magazine, April, 1899, p. 502.

on trifling as on momentous occasions. But how can we release these wasteful tensions? Manifestly the first requisite is to alleviate the mental attitude which produces them. To many it may seem heretical, but yet it seems to me true that there is too much examination of conscience, too much thinking about self in our American life. One who keeps his errors constantly before his mind's eye pursues the very best course for dissipating his forces. One cannot be looking all the time upon his own shortcomings without strain and stress of mind and body in the effort to overcome them. And, unfortunately, the more he thinks of them the more securely do they fasten themselves upon him. He rises above his lower self mainly by filling his mind with ideals outside of himself, so that he may grow up toward them. This is the only way, too, in which the machinery of life can be got to run smoothly; which fact is evidenced constantly among the people we meet in daily life. You see here a person who lives an outward life. She thinks little relatively of self, does not question unendingly whether what she does is just right and proper, whether she ought not to have done something else, whether other people's actions are intended to injure her. Her mind is full of worthy generous ends to be attained. Then observe her physical expressions: no scowling except when there is occasion for it; no rigidity of features, no constraint and formality of bearing. Rather she is free and unconstrained in all her activities; the delicate mechanisms of her being work together harmoniously and energy is expended only when work is to be accomplished. Much egoistic-introspective thinking seems to irritate the nervous system, unloosing forces which should be securely held until their services can be profitably utilized.[1]

While bodily relaxation is secured primarily through mental poise, still something may be accomplished by voluntarily striv-

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[1] We are coming to see that too great self-consciousness is a disease breeder. Faith cure, divine healing, and all the rest accomplish their good work by getting the mind of an individual off from himself. The literature of the subject is very extensive; but for an interesting study and resumé of important investigations, see Goddard: The Effects of Mind on Body as Evidenced by Faith Cures; *American Journal of Psychology*, April, 1899.

ing to let go of one's self. There is a good bit of sense in the Delsartean philosophy,[1] which holds, first, that the most vigorous individuals in intellect and character are those who are freest and most unconstrained in peripheral activities; and, second, that by proper exercises we may cultivate the power of "holding centers firm and releasing extremities." The Delsartean physical culture really helps "bottled lightning" people to take themselves less seriously. There are so many persons who, even when they rest, as they say, sit with clinched fists and rigid body, thus keeping up incessant drain on the nervous system. Let one who is conscious of tenseness in his muscles voluntarily relax at certain times of the day as a matter of discipline. This will assist in relieving the brain, and in time he will find himself relaxing unconsciously. He will find, too, that his mental briar-patch will not seem quite so thorny; he will occupy a less prominent place in his own reflections: for as mind influences body, so body influences mind.[2] Voluntarily assume an attitude and it will tend to awaken the emotion which usually initiates that attitude. Take on the bodily counterparts of fear and fear is easily engendered; while, if you stand bravely against the world, courage will be strengthened. So one who consciously puts himself into postures of rest and repose will go a good way toward securing mental quietude. As when the mind is worried it keeps the body aroused to ward off threatened dangers, or to accomplish visionary tasks; so let the body take an attitude of repose which is bred of confidence and trust that all is well with the world, and the mind will easily follow in its lead.

Wasteful muscular tensions are begotten by other agencies than a restless, worried, over-scrupulous mind. The implements we employ in our daily tasks are responsible for much useless drain upon the nervous system,—such apparently simple and harmless things as writing pens, pencils, and the like. To ap-

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[1]For an interesting presentation of this philosophy, see Annie Payson Call: *Power through Repose;* and Emily Bishop: *Americanized Delsarte.* See also O'Shea: *Physical Training in the Public Schools*, loc. cit.

[2]cf. Lee and Thomson: Beauty and Ugliness; Contempt. Rev. vol. 72; James: *Psychology, Briefer Course*, p. 383. Baldwin, *op. cit.*, p. 231, *et. seq.*

preciate the principle here involved one needs to recall what has been said respecting the hierarchal character of the cerebral mechanism. It is needful to remember especially that the "highest" brain centers exercise a general control over more fundamental ones and are charged with the management of the peripheral muscular activities. Now, it seems to be true, although it has not yet been so proven by extensive experimentation that co-ordination of the peripheral muscles involves a relatively larger expenditure of energy than coarser, less delicately adjusted movements. Thus fine needle-work is more fatiguing to most women than washing dishes, and "getting pigs out of clover" is a much greater strain on any man than playing golf or croquet. It is a rational inference, it seems to me, from the known methods of cerebral action that in the majority of people much activity of the third-level cerebral areas, those governing peripheral muscles, results in the setting free of a larger quantum of energy than is required to perform the work in hand. Peripheral muscles as they are found in the human organism have appeared relatively late in the development of the race, and the nerve centers controlling them are not yet seemingly, for most people, quite stable. Paths for the discharge of nerve force have not become deeply grooved so that much overflows into by-channels, as it were. On the other hand the fundamental bodily actions have become so habitual that they do not apparently lead to waste; the neural avenues controlling them have become so fully established that energy generated issues in profitable production for the most part.

The position here taken is by no means fully warranted by experimental evidence, and there are those scientists who feel that through habit the individual may get to be as economical in the use of peripheral as of fundamental muscles. My own observations, however, lead me to believe that in the majority of cases these conserving habits never become established in most of us. I was able several years ago to gain something relating to this point from the experience of a distinguished physician in Buffalo, a specialist in diseases of the nose and throat. Some of his work involved very delicate operations requiring most ac-

curate co-ordinations of the fingers. He said to me frequently that he never undertook such cases except in the morning hours when he was at his best; and after a relatively short period he generally was greatly fatigued, so that he felt it necessary to secure rest before continuing with his duties. On the other hand, a half day's work in his general practice which did not involve such exact co-ordinations would not overtax him. In my own case, writing with a fine pen, which must be handled tenderly in order to avoid catastrophes, soon exhausts my store of energy and of patience; and I found during the past year, while experimenting with writing pens, that an assistant and a member of my own family had experiences similar to my own.

This phenomenon is especially apparent in the case of younger people. Put a child of eight or nine to writing with a fine pointed pen and in a short time you will observe tensions in various parts of the body not employed in the writing. Soon the tongue will be extended, the hand not engaged will become clinched, the head will begin to keep time with the arm; the whole showing plainly to my mind that the co-ordinations demanded in the writing have liberated energy which is escaping into channels which should have been closed up. On the other hand, permit such a pupil to write with chalk at the blackboard and he will continue for hours without apparent over-strain. One who has opportunity to study developing children in the home will be impressed with this wastefulness of too co-ordinated activities.[1] It is recognized, of course, that with the development of the nervous organism greater delicacy and complexity of co-ordinations are possible with less of waste; but yet I believe that at no time does the average individual reach a point where he can economically practice the most exact adjustments where coarser ones would answer just as well.[2]

This leads to a few practical suggestions respecting some of the implements which are used extensively in student life. And first the writing pen. Many of our students write a great deal,

[1] See O'Shea: When Character Is Formed, Popular Science Monthly, Sept., 1899.

[2] Cf. Hancock: A Study of Motor Ability; Ped. Sem., Vol. 3, pp. 9–29.

some reporting six hours of written work a day. But this is extreme; the average is about two and one-half hours daily. Ninety-nine reported using fine pointed pens, while sixty-seven used medium pens, and one hundred and eleven used blunt points. It would be interesting to know whether those students who employ fine pens and do much writing are able to prosecute their work without fatigue; but in lieu of data upon the subject, the opinion may be hazarded that a medium or coarse pointed pen would be the means of conserving energy for the great majority of students, not excepting those who have formed the habit of using a very fine point. To repeat, though, this subject needs more extensive investigation before one may dogmatize upon it.

Believing that the matter of writing pens is a most important one for students, I have during the past two years made a test of all the pens I could secure from American manufacturers with a view to ascertaining their energetic effects upon myself and my assistant. While doubtless I have not had opportunity to examine all the good pens made, I yet feel that of those commonly in use the one of medium point requiring the least waste of energy in needless tensions is the Gillott No. 1065. It has been my experience, however, that the ordinary gold pens are far more satisfactory than those made of steel, since the point moves over the paper more smoothly, requiring less delicate management from the penman. I have been able to examine a number of fountain pens and have found the Waterman Ideal worthy of its name. Nos. 12 to 16, medium points, are well adapted to conserve the energies of the penman, as well as to gain time in writing, and they can not be too highly commended. I have also found the Parker Jointless No. 023 to be a very satisfactory pen from the point of view from which we are here discussing pens. I can write much longer and with less fatigue with these fountain pens than with any steel pen, and those who have assisted me in the experiments have had a similar experience.

"Scratchy" pens cannot be too severely condemned. Aside from their irritating influence upon the nervous system, they

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require such careful handling that waste of energy cannot be obviated. I have never known a person to write long with such an implement without manifesting fatigue in body and mind. Students who employ such articles to save expense or time in securing something better belong to the penny-wise and pound-foolish fraternity.

Another most important characteristic in a writing pen is the material of which the tip or holder is made. Metal holders are very common, although fortunately only about six per cent. of our students employ them; the others use either rubber or wood holders, or fountain pens. It may perhaps be worth saying for the benefit of the benighted six per cent. that they have adopted a most efficient plan for wasting their vitalities. When the fingers grasp a metal surface perspiration accumulates quickly, and if it be round it will tend to roll in the fingers. In order to keep it in proper position there must be increasing tension which, as any one may by trial prove to his own satisfaction, is a potent agency in dissipating energy. Let one who uses such a pen-holder exchange it for another with a cork tip, where the moisture from the fingers is readily absorbed, and he will find that too great emphasis has not been laid upon this apparently trivial matter. The principle involved applies as well to lead pencils; those with highly glazed surfaces are difficult to keep steadily in the right position without undue constraint of the fingers. The Eagle Pencil Company is now manufacturing a pencil answering the requirements in this regard. The Eagle Cortex No. 2 has a surface of cork, and I have never known a person to try it without commending it because of the ease with which it may be managed. It may be criticised in one respect only, that the lead is a trifle too hard for the greatest economy in nerve force.[1] A hard lead pencil, like a fine pointed pen, demands relatively great co-ordinations and tensions in its control, and hence leads to waste of force.

Three years ago a change was made from hard to soft lead pencils in the Franklin School, in Buffalo, and the children were

[1] As this is passing through the press the Eagle Pencil Company sends me a pencil with cork covering and soft lead, which meets the requirements indicated herein.

unanimous in their praise of the softer variety. "They are so much pleasanter to use" was the general testimony. I have examined most of the pencils of American manufacturers, I believe, and have found the Eagle Draughting to be the most satisfactory. Our students are not so wise in their choice of pencils as of pens. About seventeen per cent. of those reporting use hard pencils, while thirty-two per cent. use a medium quality. The engineers use a hard pencil almost altogether, and this is doubtless necessitated by the character of their work.

Needless muscular stimulations wherever they occur must be regarded as dissipating vital forces. Thievery of the most serious kind is constantly taking place. This is especially significant in respect of the eyes. One who has reflected upon it can not but be impressed with the marvellous delicacy required in the proper control of the visual organs. During waking life they are incessantly changing position so as to bring objects within the range of vision. In order to accomplish this they must be equipped with ocular muscles[1] so arranged as to secure movements in all directions within a given orbit.[2] In the normal eye these muscles are exactly balanced in their pulling capacities and are never active except when the interests of vision require action. But now it happens in frequent instances, so frequent as to be alarming in these last few years when investigations have been made so extensively, that one of the muscles moving an eye may be more energetic than its fellows. Or through some error in the functioning of the reflex nervous mechanism it may be active when it ought to be at rest. It tends then to pull the eye out of focus, which would render vision double if it had its way; but the will seeks to avert this calamity and so must stimulate a muscle opposed to the overacting one so as to neutralize its effect. This results then in incessant muscular strain which is a source of constant waste of vital forces.

Again, in the normal eye the lens and eye-ball are so constructed that the focus falls exactly upon the retina. But now

[1] The four recti and the two oblique muscles.

[2] See Le Conte, *Sight*, Chapters 2 and 3, for a good discussion of the muscular mechanism of the eye and the philosophy of defects. See also Cohn, *Hygiene of the Eye*, Chapters 1–8.

it occurs more frequently than not it seems that this fine adjustment is not secured. The lens has not the right degree of curvature as a whole, or in certain angles, or the eye-ball is either too short or too long, when the focus falls in front of or behind the retina, or is not the same at every angle. The mind tries to remedy any error of this sort by modifying the lens through the delicate ciliary muscles. In a defective eye this stimulation must go on incessantly, and one can easily imagine its effect in draining the organism of its vitality. Every one has heard in these recent years that the eye is the source of all disease; and while this is doubtless an exaggeration, it yet emphasizes a certain truth of vital importance to every individual, but especially to the student in whom defective vision entails most serious consequences, alike in blocking one important approach to the mind and in robbing the system of its energy.[1] In the defective eye these muscular tensions go on hour after hour, and only the most hardy constitution can endure the strain. This is evidenced in a striking way in the sudden increase in eye defects during adolescence. A great many boys and girls realize that they have eyes at this time.[2] The organism is now devoting its strength to the building of heart and lungs and bones and cannot expend so much in disciplining refractory eyes, when their baneful effects become apparent. So, too, in sickness people are conscious of eye strain that they have not noticed before and which they are never really conscious of except when the energies of the organism are at a low ebb. Swift[3] observed this phenomenon frequently in his study of vision in the Normal School at Stevens Point, Wis. He says:

"An interesting fact, though by no means a new one, was repeatedly observed. Young boys and girls with more defect than some older ones had never experienced any trouble with their eyes, while the older ones, with much less defect, were constantly annoyed by eye ache or the blurring of the letters. The difference was that the vigorous nervous system of the young boys and girls was able to sustain the irritation of the poorly constructed eye and, by an over supply of nerve force, could

[1] See for an excellent discussion of this subject: James, *Suggestions to Teachers Regarding Visual Defects of School Children*, Mankato, Minn. Also Ranney, in New York Medical Journal, June 11, 1892.

[2] See, *Some Adolescence Reminiscences*, O'Shea, Journal of Pedagogy, Oct., 1898.

[3] Pedagogical Seminary, October, 1897, and reprint.

compel the eye to do its work without apparent injury, while the more exhausted nerve centers of the young men and women could not stand the constant call for more energy. 'Disease is localized abnormal innervation and always central in the nervous system, being a lack of excess of motive force.' It should not be forgotten, however, that eye strain is a potent factor in this disturbance of the nerve centers."

One observing students on the campus of our University is impressed with the number who are not spectacled. Whatever opinion he may hold regarding the relation of spectacles to mental attainment he must at least conclude that many students are wasting energy in combating visual defects that ought to be remedied by glasses. Investigations made within the last decade in various parts of our own country and Europe[1] show that on the average at least 30 per cent. of individuals have defects of vision which require correction by lenses. And the defects increase with age; as high as 40 or 50 per cent. of the children in the upper grades in some places have defective sight. According to Sherzer:[2]

"An examination of the eyes of over 5,000 school children and students in Germany, France, Russia, England, and the United States, has shown that as we pass from the lower to the higher grades there is a gradual increase in the number of cases of myopia and in the degree of the defect. The German government in a recent examination found that in the elementary schools from 5 to 11 per cent. of the children are afflicted; in the higher schools for girls, 10 to 24 per cent.; in the Real Schulen from 20 to 40 per cent.; in the Gymnasia from 30 to 50 per cent.; while in the universities the percentage may run up to 88."

According to Cohn[3] myopia increases rapidly with age in the German schools; "in the real schools the myopia percentages from the sexta to the prima were 9, 16.7, 19.2, 25.1, 26.4, 44; in the gymnasia 12.5, 18.2, 23.7, 31, 41.3, 55.8." Professor Swift's[4] researches seem to indicate that nearly every student examined had some visual defect. Investigations in the schools of Sioux City, Iowa, show something like 50 per cent. of de-

[1] See Cohn, *op. cit.*, Chapters VIII and IX, for many tables presenting the results of examinations in various countries.

[2] *Rules for the Care of the Eyes;* published by Michigan State Normal School.

[3] *Op. cit.*, p. 57.

[4] *Loc. cit.*

fectives in the highest grades. In Rochester, New York, 31 per cent. of the children in the high schools have defects of vision which could be detected without any expert examination. And so it goes. Prentice,[1] Cohn,[2] and others have recently shown beyond a doubt that no individual can afford to go through life without ascertaining the condition of his eyes; and yet 40 per cent. of our students report that they have never had their eyes examined. It would indeed be a remarkable circumstance if there was not stealthy thievery of nervous energy taking place constantly in a number of these cases.

Because one is not conscious of a defect is not conclusive evidence that he does not possess it. I take my vision to be the standard, the normal, unless somebody has shown me better. If I am born with a myopic eye and can scarcely see my hand in front of me, I have no way of telling that I am not as other people are. The only safe course is to have my vision measured up to a norm or standard; and if it does not fulfill requirements to call to my aid the skill of the oculist and of the optician.

For the most part the eye has been used throughout racial history in discerning relatively large objects and those at a distance. It has been only within the most recent period that such visual co-ordinations have been required as are necessitated in our day in the reading of print. Authorities agree that a child of five or six, for instance, has not developed the visual capacities to read ordinary print with safety.[3] When a child of this age is set to studying a primer, printed in the type that such books usually are, or at least have been in the past, he not only suffers great strain, but injury is apt to result to the visual organ. Now it is probable that even in adult life the reading of fine print requires co-ordinations of ocular muscles which result in dissi-

[1] *The Eye in Its Relation to Health.*

[2] *Op. cit.*

[3] See, for instance, Oppenheim, *The Development of the Child,* Chapter V; also Dewey, The Fetisch of Primary Education, Forum, May, 1898. Indians are said to have difficulty in accommodating their vision to print.

pation of nervous force. Cohn,[1] Sanford,[2] and others have calculated the size and shape of letters which can be read with greatest ease. Burnham[3] summarizes the results of investigations upon this subject in an excellent way and his words may be quoted:

"1. *Size of the Letters.* It is necessary that type be easily legible at a distance of twenty inches. For this it is necessary, according to Dr. Cohn's estimate, that the letters be 1.5 mm. high. 'Any type that is smaller than 1.5 mm. is injurious to the eyes.' An angle of five minutes is sufficient for the recognition of a letter; hence, according to the estimate of Dr. Weber, a healthy eye can read clearly a letter .7 mm. in height without extreme convergence; but such reading is very laborious. Weber tested the time occupied in reading with different types. When the size of the letters was greater than 2 mm., he found that the speed of reading was retarded. He decided for a minimum of 1.5 mm. Eulenberg and Bach demand still larger type for the lower classes. Many of the school books in common use have much smaller letters than Weber's minimum. In some of the school atlases, letters only .5 mm. in height are used. Many very beautiful maps also have very small type. Especially before pupils have become familiar with the letters, it is necessary to have large type. Javal wishes to have it determined by experiment how large the type should be in the different classes in order that no pupil, however bad the light, need bring his eyes too near the book.

"2. *The Thickness of the Letters.* 'No print of which the down stroke is thinner than 0.25 mm. should be tolerated in school books.' In Latin type the corners of the letters should be strengthened in order to make them appear rectangular, otherwise by the irradiation of the white ground they appear rounded off.

"3. *The Shape of the Letters.* Javal points out that, if the lower half of a series of words be hidden from view, it still is easy to read them. But when the upper half is covered, it is difficult, often impossible, to do so. In reading, we glance along the line at a little distance above the center of the letters; and the letters g, j, p, q and y are the only ones that come below the line. Thus the upper part of the letters are of special importance. As the result of an extended research, Dr. Sanford found several groups of letters in our alphabet that are relatively poor. Of the small letters c, e, o are confusable with one another; a, n and u are poor letters; and s, i, l, t are liable to cause confusion. Javal, Cat-

[1] *Op. cit.*, Chap. XXIII.

[2] The Relative Legibility of the Small Letters, Am. Jour. of Psychology, Vol. I, pp. 402–435.

[3] *Op. cit.*, pp. 49–51.

tell, and Sanford have each suggested changes for improving the form of some of the worst letters. Among the most important of these are Javal's suggestion that letters be made broader, and that we return to the more open forms of c, e, and o, and Sanford's suggestion that a letter in shape of an inverted v or of a small cap A might be substituted for our present small a.

"4. *The Approach.* The distance between letters and words, or the approach, is important. Every letter stands out with especial distinctness when the space between two letters is wider than the space between the ground strokes of the letter. For this reason words are emphasized in German by spacing the type. This greater approach adds to legibility. School-books should have an approach of nearly 1 mm.

"5. *'Leading' Is Important.* 'A book has good interlineage,' according to Dr. Cohn, 'when, if the letters are 1.5 mm. high, the lines are 3 mm. apart.' A distance of 2.5 mm. (1–10 of an inch) is the smallest admissible. Many of the old books had wider interlineage than is usual at present.

"6. *The Length of the Lines.* The shorter the line the more easily can one read. Javal thinks the long lines the cause of progressive myopia in Germany. According to Dr. Cohn, the greatest length of line should be only 10 cm. Weber would have lines from 14 to 15 cm. in length.

"Dr. Cohn resumes his rules as follows: 'In the future I would have all school authorities, with measuring rule in hand, place upon the *Index librorum prohibitorum* all school-books which do not conform to the following measurements: The height of the smallest "n" must be at least 1.5 mm. (.06 inches), the least width between the lines must be 2.5 mm. (.1 inches), the least thickness of the "n" must be .25 mm. (.01 inches), the shortest distance between the letters .75 mm. (.03 inches), the greatest length of text-line 100 mm. (4 inches), and the number of letters on a line must not exceed 60.' "

It is of course difficult for a student to alter the type of his text or reference books, and attention is directed to the matter here chiefly in the hope that those who have the choosing of such books may take this energeic question into consideration. It is of especial significance perhaps to students in the languages who have occasion to consult dictionaries freely.

Attention has been directed thus far to the waste entailed by needless tensions resulting from a worryful mind, from the use of implements requiring unnecessary co-ordinations, from de-

fective vision, and from too concentrated employment of the eyes. Before leaving this general topic, a word should be said regarding another factor in the causation of wasteful tensions. The human body in a standing or sitting position is, as everybody knows, acted upon by gravity, and if it be thrown out of plumb, so to speak, it tends to fall to the earth. This catastrophe can be averted only by the action of muscles which pull against gravity, and so serve to keep the body in equilibrium. Suppose now a person on foot or in his seat in such a posture for some time that gravity has a leverage on him, and his muscles are doing their best to prevent his falling; it is easy to see what this means in terms of nerve force. It involves nothing less consequential than a ceaseless drain upon the system. People who do not habitually stand or sit in such manner that the body is poised, as it were, and at rest will certainly suffer for their error in lessened efficiency in both physical and mental work.

This principle is of special value to a student as it relates to the position he habitually takes while engaged in study. In order that this position may comply with the requirements of economy in the expenditure of nervous energy, the study desk and chair must be exactly adjusted to the bodily measurements of the individual so that while using them there may be little occasion for muscular strain. No statistics have been gained regarding local conditions in respect of this matter, since in order to be of value they would require considerable exact measurement and this we could probably not have secured; but it is not unreasonable to suppose that students have not accidentally and in all cases hit upon the proper regulations respecting the height of desk and chair and their "distance" relations to each other. Now, recent investigation has established something like a law of hygienic seating Lincoln,[1] Barnard,[2] Marble,[3] and others in our own country and many scientists abroad[4] have given much attention to this subject during the past few years, alike in the study of the physiological conditions which should govern seat-

[1] *The Sanitary Conditions and Necessities of School-houses and School Life.*
[2] *School Architecture*, New York, 1860.
[3] *Sanitary Conditions for School-houses.*
[4] See The Pedagogical Seminary, June, 1892, for a summary of investigations.

ing and in the detailed measurements of many thousands of individuals of different ages to ascertain in a general way the requirements for persons of different ages. Meyer's statement[1] of principles is as follows:

"The two seat-bones are curved like a bow; a line joining the lowest points of these two bones is called the seat-bones line; the center of gravity of the body is in front of the ninth or tenth chest vertebra; and a straight line from this point to the ground is the line of gravity. Upright sitting is possible only when this line passes through the seat-bones line. This line determines the surface of support for the body. But the least movement that displaces the center of gravity makes upright sitting impossible without great muscular effort. The surface of support is then determined by some third point. In a forward-sitting posture the line of gravity falls in front of the seat-bones line, and the third point that determines the surface of support is given by the edge of the form, or when the seat is not broad, by the point where the feet come in contact with the floor, or by both points together. The line of gravity may now fall on that surface which is determined by the front edge of the seat and by the muscular effort required to keep the body in equilibrium. Hence the nearer to the knee the seat extends, the larger the surface of support and the easier it is to retain the equilibrium. All the demands for an upright sitting posture would now be satisfied if the trunk were immovably fixed in the hip-joint, but it is joined movably to the thighs; hence the upright posture can be maintained only by the work of the pelvic muscles. The muscles soon become fatigued and the body would fall forward unless supported by leaning the chest and arms against the table.

In the backward-sitting posture, in which the line of gravity falls back of the seat-bones line, the end of the coccyx is the third point which determines the surface of support. This position has the great advantage of having this third point fixed and immovable. The body with this backward inclination should be supported by a back rest. This may be placed against the shoulders, but then the position is a half-reclining one. The lower down it is placed within certain limits the more it helps in an unright posture. Placed at the upper edge of the hip-bone, or back of the last vertebra, it holds the pelvis and the trunk in an upright posture. The principle then is as follows: A pupil must always take those positions in sitting in which the line of gravity falls a little back of the seat-bones line. The upper part of the body also must be supported. It is easy to determine the kind of seat that should be used in accordance with this principle."

[1] Summarized by Burnham, *op. cit.*, p. 40.

All that can be attempted here in this discussion of seating is to direct the attention of the student to the importance of the matter in the hope that he will try to arrange his chair and desk so as to save nervous wear and tear to the fullest possible extent. One suggestion may be made, however, that there should be a back-rest to the chair, and it should support the back under the shoulders and above the hip-bones. In Saxony there is a state-regulation to the effect that school seats must be provided with shoulder rests and cross back-seats. The distance of the chair from the edge of the desk should be such that the student while sitting erect can place the fore-arms on his desk without stooping or without elevating the shoulders. In order to meet this requirement the top of the desk should overlap the seat by two or three inches—there must be a "minus" distance, in technical phraseology. This is rarely found, in my experience, in students' rooms, for the reason that it involves some bother getting free from the desk; but the greater comfort thus ensured, and the energy conserved would more than outweigh the slight trouble which such an arrangement would occasion.

The matter of seating is of consequence not simply from the point of view of saving energy, but it has an important influence also upon the generation of force. A student leaning over his desk, with his lungs constricted and the arteries leading to the head compressed, is in a good way to foster mind wandering and napping. The organism then becomes clogged, as it were; it does not receive its due of oxygen, as a result of which the brain must certainly become seriously handicapped.

§2. *The Daily Program.*—During the past decade a great deal has been said, alike in the educational and in the secular press, regarding over-pressure in education. Physicians and educators have noted with great apprehension the apparently increasing number of pupils in the higher schools who are deficient in that vigor and robustness of body and mind which are essential for success in the battle of life. We are told that nervous diseases are much more frequent in youth today than they were a generation ago, and the fault must lie with the

schools; they pass the safety line in the demands they make upon their pupils. This feeling has been so marked and wide-spread that investigations have been prosecuted in Europe, and to some extent in our own country, to ascertain the true condition of affairs respecting the amount of work required of students. Thus far little of definite scientific value has been attained; but yet the conviction is deepening in the public mind that education is too much of a forcing process which calls upon energies that should be utilized in the growth of vital organs. Physicians have been urgent in their demands that the work of the schools be lightened. Oppenheim[1] is unsparing in his criticism of the present regime as it exists in the lower grades. Keating,[2] after long experience with diseases of children, finds that many of them have their origin in excessive strain incident to school work, and he too insists upon reform. Examinations of the school children of Germany have shown that in some instances they return to their work day after day with constantly increasing fatigue;[3] recuperation cannot take place fully during periods of release from recitation and study. While, so far as I am aware, no researches of just this character have been made upon fatigue in university life, yet many persons of good judgment are confirmed in the belief that even here students are overworked, and suffer in consequence thereof in some such way as do overtaxed children in the lower schools.

Some effort has been made to determine the amount of study which may be safely undertaken by a student at different stages in his progress through the schools. It must be apparent, however, that it is impossible to formulate any general law respecting this matter. Individuals differ so greatly in the amount of energy which may be expended in intellectual and physical activity that no rule could apply to all. Again, the kind of work done and the conditions under which it is prosecuted must exercise an important influence upon the readiness with which energy is expended. Some investigators are of the opinion, though,

[1] *Op. cit.*, Chapter V.
[2] *Mother and Child*, pp. 180, 219, 220.
[3] Kraeplin: A Measure of Mental Capacity, Pop. Sci. Mo., Vol. XLIX, p. 758.

even regarding these varying and modifying factors, that university students on the whole cannot undertake with safety more than eight hours a day of difficult intellectual labor.[1] It is important to note, however, that during these eight hours the attention is to be concentrated upon mental tasks; mind wandering and reverie are not to be considered as work. If we compare the stint of our students with this as a sort of standard we find that some work too much, while others do not tax their energies to a legitimate extent. One student reports one hour spent in study; four, two hours; twelve, three hours; thirty-four, four hours; fifty, five hours; seventy-two, six hours; thirty-nine, eight hours; eleven, nine hours; thirteen, ten hours; four, eleven hours; one, fourteen hours. It is probable that the students reporting one or two hours devoted to study did not take into account time spent in the laboratories, so that their estimate is of no value to us here. About all that can be said is that students working ten, eleven, and fourteen hours a day are likely to draw too heavily upon their resources.

And yet it should be remarked in passing that the injurious effects of study upon the health of students is in all likelihood due more largely to the unhygienic conditions under which the work is carried on than to mental application itself. It seems to be true that during waking life the mind is constantly active in some direction; and if study could be done under proper conditions, it is probable that it would be no more fatiguing than other sorts of mental occupation. It seems to me it is really not so much a question of the amount of study as of the circumstances under which the study is carried on;[2] except, of course, that if one spends fourteen hours a day over his books he cannot meet the requirements in respect of exercise and sleep discussed above.

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[1] See a summary of six articles on mental fatigue, Psychological Review, Vol. IV, p. 548, *et. seq.* President Elliot recommends his students to spend but eight hours in study. Kellogg, in Good Health for March, 1900, says the old rule of eight hours for work, eight hours for exercise and meals, and eight hours for sleep, is one that ought to be obeyed by every person.

[2] See O'Shea: The Hygiene of School-work; Kindergarten Review, May, 1899.

Looking now at some of the regulations in accordance with which one's study should be prosecuted, it may be seen that one of the most important requisites for economy is the concentration of attention upon any given topic for unbroken periods, differing in length with individuals, with age, and with the nature of the subject attended to. Common-sense tells us that one may accomplish more with less effort when he holds his mind to a task than when it is constantly wandering into by-paths; and neurology has produced some evidence giving warrant to this view. It has pointed out that there is what one might call division of labor in the cerebral factory. In one section is carried forward a certain variety of work, in another a different kind; and so each department has its special duties.[1] Now if one be attending to mathematics, for instance, it is probable that a special department of the brain is particularly active. The memories and the associative functions in that region are aroused and energetic. And the longer one holds his attention to this subject, up to a certain point, the clearer are obscure relations discerned and the more rapidly does thought proceed. In a neurological sense this means that the inertia of the brain in a special area is overcome and energy moves along desired lines with less resistance than at the outset. But now let the attention wander unbidden into another field; it must arouse inactive regions of the brain that for the time being ought to remain dormant. This dissipates both time and vital force.

It must be familiar to every one that solving a problem and learning a poem at the same time is bad economy. So, too, it is a wasteful practice to try to master one's psychology or literature or mathematics while listening to the conversation of a room mate, or while one's mind is idly straying off into neighboring regions of either study or anticipated pleasures. The conservation of mental energy requires that a student should have certain periods when he is wholly uninterrupted and can give his

[1] See Donaldson, *op. cit.*, Chapter on *Localization of Function* for an exposition of the theory. The literature of the subject is very extensive and any one interested might consult Flechsig, *op. cit.;* Ferrier, *Localization of Function.* Munk, Horsley, Schäfer, Hitzig, Meynert, Brocca, *et al.*, have written much on the subject.

attention absolutely to the task in hand. He should put out of sight and hearing every stimulus which tends to distract attention. One cannot urge too strongly the desirability of fraternities and rooming houses having a rigid law that during certain study periods there shall be a gag on every mouth and a millstone attached to every heel.

A large number of our students—over forty per cent.—reported that their study periods are interrupted; some have only a very brief period during which they are certain of being unmolested. Five reported one hour that could be given without interruption to study; twenty-two, two hours; forty-seven, three hours; fifty-four hours; thirty, five hours; twenty-eight, six hours; thirteen, seven hours; five, eight hours; one, nine hours. Engineers have little time that is given uninterruptedly to study aside from their laboratory work. This report indicates a need of reform, for more reasons than one, too. It has already been said that interruption involves waste; but it has an even more serious psychological effect. In order to discover the deeper relationships existing between ideas in any field one must have long periods for reflection. It is to be feared that many of our students do not have leisure to explore the depths of the subject which they study; they simply attach ideas to the mind in a sort of tangential fashion through the exercise of the verbal memory. Reason seems to prosper only in relatively long periods of application, while the mechanical memory may utilize profitably mere snatches of time.

While economy demands uninterrupted periods for study, yet this does not mean that the student should apply himself five or six or seven hours without any relaxation. On the contrary investigations by Burgerstein,[1] Holmes,[2] Kraeplin,[3] and others show that greater progress is made in the intellectual operations if attention be not constrained to a given task beyond the point of fatigue.[4] If at the approach of fatigue the attention be released for a time it will return with renewed vigor and in the

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[1] Ped. Sem., June, 1892, pp. 60, *et. seq.*
[2] Ped. Sem., Vol. III, pp. 213–234.
[3] *Loc. cit.*
[4] Cf. Newsholme *op. cit.*, p. 66. Also Kotelmann, *School Hygiene*, Chap. XIII.

long run accomplish more than if it be held continuously regardless of cerebral wear and tear. Efforts have been made to ascertain the span during which attention can be profitably held to a subject; but as in the case of the amount of work which can be done, the result must be purely relative; it depends upon the subject and upon the individual. It is thought by some, though, that in general fatigue intervenes after twenty minutes concentrated effort in the early years and sixty minutes or thereabouts in maturer life.[1] It is probable, however, that a vigorous adult possessing a well organized brain can apply himself to one subject for a longer period than an hour. Experience and the principles of neurology both warrant the hypothesis that energy generated in one part of such a brain may be utilized readily in carrying forward work in other regions.[2] But the association fibers which make possible the easy transmission of energy from one cell to another do not apparently attain their complete development until about the age of thirty-three, as is indicated in Fig. 17.

Now if the assumption be true that the associative fibers serve as energy-carriers between the various cerebral departments, and these fibers are maturing constantly until middle life, then it follows that the Senior in the University should, other things being equal, be able to apply himself with profit for longer periods than the Freshman. But it is certainly impossible in the present state of our knowledge to say just how long should be the study periods of either the Senior or the Freshman. All we are warranted in saying, which is far from as definite as can be desired, is that attention should be concentrated upon a single subject at a time and held to it until the approach of fatigue, when it should be released. If the same study is to be continued, a break of ten minutes passed in moderate physical activities will aid in the removal of worn out materials from the brain and in securing a fresh supply of blood in the cerebrum. It is

[1] See Ped. Sem., June, 1892, pp. 64 and 65.

[2] Flechsig: *Gehirn und Seele*, presents strong evidence in favor of the view that energy generated in one part of the brain may be put to use in remote regions. See also Curtis: *Inhibition; Ped. Sem.*, Vol. VI, No. 1, for a valuable discussion of the subject.

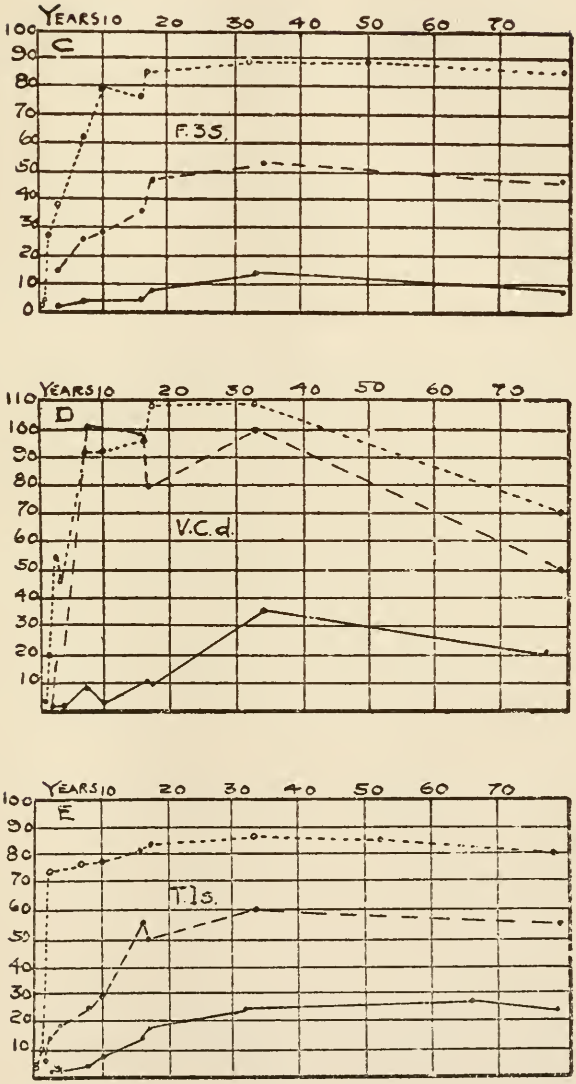

FIG. 17.—Charts showing the increase in the medullated fibres in the three layers of the brain during the growing period and the decrease in advanced age. Birth, to 79 years (modified from Vulpius). C, third frontal gyrus, left side; D, anterior central gyrus, right side; E, first temporal gyrus, left side, ... outer layer; ...., middle layer; ...., inner layer. (Donaldson.)

important, though, that the relaxing exercises should not demand just as great concentration of attention as the study; the purpose in relaxing, which was argued in the preceding chapter, is to relieve the will, to set it free, when it will return with renewed vigor to mental tasks.

The sequence of studies in the day's work is an important subject for the student. The principle governing this matter is dependent upon the neurological fact already discussed, that different regions of the brain have charge of characteristic mental activities. When then the mathematical center has been exercised for a reasonable period, economy would suggest that this be relieved while other areas be employed. To follow one mathematical study by another is not the part of wisdom unless the first has used but a fraction of the available energy. If it were possible it would be advisable to keep the attention concentrated upon a subject, as mathematics or literature, until the energy which can be utilized in that direction is largely spent; then turn to another study of a different character. This is not so important for the mature as for the immature brain-worker; a Senior should be able to disregard the law of sequence in studies with greater impunity than a Freshman. He can draw more largely upon all his resources for special purposes; he can summon most of his strength, totalize it, as it were, on occasion. But yet even with the upper classman prudence would advise arranging the day's program so that studies employing different mental activities should relieve one another. This is especially important in relation to the mental and motor branches. If a student has to prepare three subjects during the day, two of which require much writing and the third none at all, it would doubtless be best for him to put the non-writing subject between the others, so that the cerebral motor regions employed in writing may perform the required tasks without exhaustion.

A student does not have entire option respecting the hours of the day which can be spent in study, but yet the matter is under his own control in some measure. A few of our students have contracted the habit of visiting in the forenoon and study-

ing at midnight, going on the principle that one hour is as good as another for study and the fresh morning hours are the best for social pastimes. But practically all those who reported testified that their minds worked best in the forenoon; eighteen reported being best in the afternoon, while two found they could accomplish more at 5 o'clock in the morning than at any other hour. The best hours ranged from 7 to 12 in the forenoon, while the choicest period of the day is from 9 to 11. These hours accord with investigations made by Lombard, although his results are not by any means conclusive, since too few subjects have been studied and disturbing factors such as the influence of alcohol, tobacco, and food, make his data in a measure unreliable. Still his curve showing the rhythm of daily fatigue is at least suggestive, and may be given here:

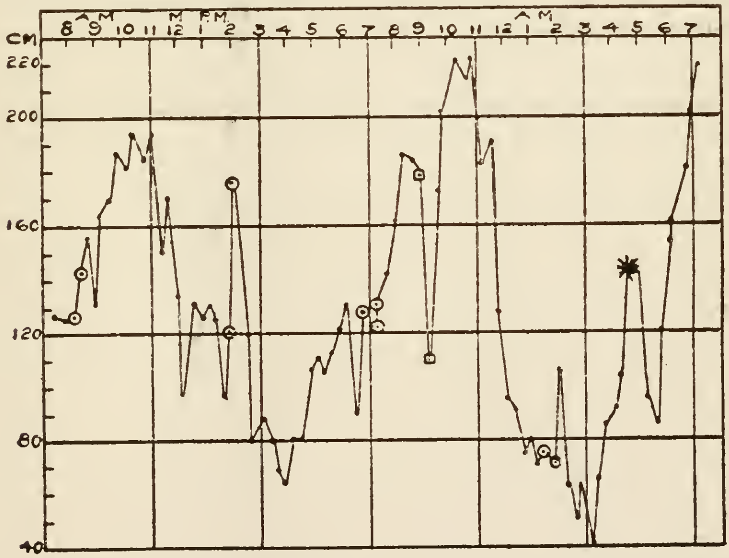

FIG. 18.—Showing at each hour of the day and night how many centimeters a weight of 3,000 grammes could be raised by repeated voluntary contractions of the forefinger before fatigue set in. The curve is highest at 10 to 11 A. M. and 10 to 11 P. M. Lowest 3 to 4 P. M. and 3 to 4 A. M. Circle with dot observation made just after taking food; square with dot smoking;* work done eight minutes after drinking fifteen cubic centimeters of whisky. (Donaldson after Lombard.)

There can be little doubt that for most people the morning hours are the most profitable to be devoted to diligent, concen-

trated study. The afternoon hours can be employed to greater advantage in duties demanding less energizing of the will; while in an ideal program the evening hours will be spent almost wholly in relaxation. Considering the number of hours our students devote to study they would, it seems, have ample opportunity to accomplish all of their tasks during the day if they would economize in the ways that have been suggested. The arrangement of a program on this basis is very desirable from many points of view, social and otherwise; but one point especially needs to be made here. It is probable that much study late at night results in a disturbance of sleep. Ninety-three students reported that their sleep was greatly disturbed by dreams; and while people who do not study at night dream, still it is certain that intense mental application throws the brains of most people into an excited condition which is inimical to refreshing sleep. People who dream much waste nervous energy; the mind is active but without profitable outcome. For those who dream after night study it would surely be better economy to work intensely during the day and devote the evening to relaxation and social pleasures which will woo Morpheus to their bedsides when the day is over.

The majority of our students do not usually study later into the night than is ordinarily thought to be healthful. Two reported not studying beyond 8 o'clock; forty-four worked until 9 o'clock, one hundred and eighty-seven until 10 o'clock, seventy until 11 o'clock, nine until 12 o'clock, and one until 1 o'clock. One hundred and four students have studied all night on occasion. Eighteen of these said that it did them no harm, while eighty-six felt "bad, sleepy, dull, tired, ragged," and had no ambition to work the following day. Forty of those who studied very late into the night testify that the knowledge they acquired remained with them; fifty-eight said that in the morning it, like the Arab, had folded its tent and silently slipped away.

§3. *Tell me what company you keep and I will tell you what you are.*—Most of us have little appreciated the importance

of this old adage, although we see its truthfulness illustrated every day of our lives. We realize that we gradually become like those with whom we associate. I cannot be in the presence of a friend without unconsciously but yet surely incorporating into my own activities his peculiarities of voice, facial expression, carriage, gesture, and so on. The subconscious phase of personality seems to be charged with the responsibility of making the individual like his environment. When he looks upon a face showing constraint of lips and eyes, he tends to reproduce these tensions in his own features; if he listens to a high-pitched, raspy voice, he feels a strain in his own vocal organs. And so it goes, throughout the whole gamut of human activities; people that go together get to act and even look alike![1]

Physiologists in our day are calling attention to the vast importance in human life of this method of suggestion or imitation, whereby we take as copies the people around us and mold ourselves upon them;[2] and it is of especial importance as it relates to the economy of vital forces. When we are in the company of people who are fatigued, who are over-scrupulous, fussy, tense, and constrained in all their expressions, we quickly reproduce their tensions and so waste energy. Most of us instinctively avoid these "bottled lightning" people, these nervous hypochondriacs; the preservation of life demands it. Now, a student cannot always determine the company he keeps, but yet he is in a way master of the situation; and if he be of the type easily suggested to he should above all things avoid living in the same quarters with a neurotic individual, for if he does his forces will steadily run off without profitable issue. To choose a well-poised and well-nerved room-mate is one of the most important undertakings which can engage the attention of a student. If it should be asked, what will become of the

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[1] See for a great many illustrations of this law, Russell: *Imitation and Allied Activities;* Small: The Suggestibility of Children, Ped. Sem., Vol. IV, No. 2; Sidis: *The Psychology of Suggestion,* Parts on Normal Suggestion and Social Suggestion.

[2] See Baldwin, *Mental Development, Methods and Processes,* Chapters VI and IX, X, XI, XII; Vernon Lee and C. A. Thompson: *Beauty and Ugliness,* Contemporary Review, Vol. 72, pp. 544–569, and 669–688; Scripture: *The New Psychology,* pp. 248–261; Wundt: *Human and Animal Psychology,* pp. 323–339.

neurotics, it must be answered that the law of the survival of the fittest should have its way in student bodies as elsewhere. At any rate it is a sacred duty to conserve against injury from any source the best, whether moral or physical, that has been given to us in human life.

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BULLETIN OF THE UNIVERSITY OF WISCONSIN

NO. 33

SCIENCE SERIES, VOL. 2, NO. 3, PP. 199-246, PLS. 3-15

CONTRIBUTIONS FROM THE ANATOMICAL LABORATORY OF THE UNIVERSITY OF WISCONSIN

EDITED BY

WILLIAM S. MILLER

Assistant Professor of Vertebrate Anatomy

Published bi-monthly by authority of law with the approval of the Regents of the University and entered at the post office at Madison as second-class matter

MADISON, WISCONSIN

FEBRUARY, 1900

PRICE 40 CENTS.

Bulletin of the University of Wisconsin.

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CONTENTS.

INTRODUCTION.

The University of Wisconsin requires that each student shall, before graduation, write a thesis on some subject selected either by himself or the professor under whom the work is to be done.

The subjects of the following four papers were suggested to the students, named below, of the class of 1898. The results of their work were so satisfactory that I have quite largely incorporated them in the present Bulletin.

The description of the vascular system of *Necturus maculatus* I hope will be of assistance to those who use the animals in their laboratories. For several years I have used them in my course in vertebrate anatomy, and feeling the need of some detailed description of the blood-vessels, I kept notes on each animal used. The results, as embodied in the present paper, represent the dissection of over 200 animals and cover four years' work.

Those who have used *Necturus* in laboratory courses know how variable they are. The text and diagrams represent the most constant type. I regret that I have not been able to consult what is practically the only work on *Necturus* that is known to me, "Ontleed en dierkundige bydragen tot de Kennis van Menobranchus, den Proteus der Meeren van Noord-Amerika." J. van der Hoeven. Leiden, 1867.

I should be very glad to receive any corrections which other workers find desirable on comparison with their own notes; also suggestions on the nomenclature, which I realize is faulty in some places.

The following gentlemen of the class of '98 have assisted in the preparation of these papers:

H. W. Ochsner: The Lung of *Necturus maculatus.*

A. Sauthoff, J. H. Van Vorhis: The Vascular System of *Necturus maculatus.*

C. A. Squire: The Brain of *Necturus maculatus.*

A. W. Meyer. The Epithelium of the Peritoneal Cavity of the Cat.

These papers by no means represent all the worthy work done in the Laboratory. Some of the subjects are being worked out gradually; a few points this year, a few more the next and so on until at last they can be gathered up into a complete paper.

THE LUNG OF *Necturus maculatus.*

The lungs of *Necturus* consist of two long, narrow, transparent membranous sacs, which extend backwards into the abdominal cavity dorsal to the other viscera. Their outer surface is perfectly smooth and is covered by a layer of the peritoneum lining the pleuro-peritoneal cavity, thus forming a mesentery which attaches them to the dorsal body wall along almost their entire length. In a full-grown specimen, whose lung is from 100–125 mm long when distended, less than 25 mm is free. Each lung is a perfectly simple sac, no septa being developed, and their cavities open into the pharynx through a common membranous tube running in the dorsal wall of the pericardial cavity. This tube represents the trachea of higher vertebrates.

The epithelium, which forms the outermost layer (serous layer) of the lung of *Necturus*, varies in size and outline in the various parts of the lung, as may be seen from Pl. 3, figs. 1, 2; Pl. 4, fig. 3. Between the large blood-vessels and especially in the anterior part of the lung, the epithelium is of the common type, as shown in Pl. 3, fig. 1. It consists of large, thin, irregular cells with comparatively smooth boundaries. The nuclei of these cells do not seem to occupy any one characteristic position, but are found in all parts of the cell. Toward the posterior end and along the sides of the blood-vessels we find the cells taking on a longer and a narrower shape, making them irregularly oblong, as shown in Pl. 3, fig. 2. The nearer we approach the tips of the lungs, the narrower and longer do the cells become. Between the lateral branches of the blood-vessels we very often find whorls of cells, centering around a rather large irregular one. Covering the blood-vessels and lymphatics we

have an entirely different type of epithelial cell, as shown in Pl. 4, fig. 3. The cells are often extremely long and always have very jagged edges, more so than the figure indicates. Between these types we find all gradations, though the last type passes over into the others very abruptly, as a rule.

In all my specimens I was not able to see a single spot or orifice which I could construe to be a stomata. It is true that there were some small spots in some of the preparations, but they could always be traced to over distention, tearing, or drying of the lung. Indeed, they could be produced in any quantity by just such procedures.

Along the inner side of the lung, near the pulmonary vein, pigment cells are often found which present many bizarre shapes.

THE PULMONARY EPITHELIUM.

If a *Necturus* be killed by cutting off its head and one of its lungs be removed, cut open and spread out on a slide in salt solution, and its inner surface examined under a medium power, it will be seen that the epithelium is apparently collected into groups or islands of cells which are surrounded by clear spaces. This arrangement coincides with that given by Schulze, Schmidt and Ranvier for the frog, and by Williams and Stirling for the newt.

Schulze describes the relation between the capillaries and the epithelium of the lung of Reptiles and Amphibians as follows:

"All respiratory capillaries are attached to the alveolar wall only on one side. They would project freely, with their greatest circumference, into the air cavity, if they were not completely covered by a continuous plate-like epithelium. The large polygonal cells of this alveolar epithelium, meeting accurately at their sides, cover the surface of the capillaries, turned toward the air cavity, with thin, transparent, plate-like expansions and send plug-like continuations, generally the nucleus with some surrounding protoplasm, into the capillary network and indeed so far down that they reach the connective tissue stroma of the alveolar wall, and so completely fill the spaces of the capillary network. These plug-like continuations, harboring

the nucleus and protoplasm of every cell, are usually found in the corners of the single cells, so that several plugs lie together and are found in a single capillary mesh. Still, many cells are also found which bear their granular continuations nearer the middle and completely fill a capillary mesh."

Williams says:

"The epithelial scales which cover the capillary areas of the lung of the newt (parts which coincide with air-cells of the mammalian lung) lose not only the external appendages (cilia), but also their internal parts (nuclei and granules). This successive reduction leaves nothing but a hyaline involucrum enclosing a pellucid fluid."

Stirling also investigated the lung of the newt and says:

"The arrangement of these cells is curious. They lie in groups, and the large nuclei occupy the small spaces left between the blood-capillary network, whilst the thin plates of each cell cover the capillary wall. The result of this arrangement is that the air in the lung is separated from the blood-stream merely by the cell plate of these cells and the squames which form the capillary wall."

If now the remaining lung be carefully removed and stained by means of nitrate of silver, the outline of the cells and their nuclei will be brought into view. Pl. 4, fig. 4, shows the outline of the cells, also that of the islands in which the nuclei and protoplasmic part of the cells are situated. Pl. 5, fig. 5, shows the relation of the nuclei and protoplasm to the cell boundaries in a case where several nuclei are found in a single mesh of the capillary network. Sometimes we find a single nucleus filling the whole mesh and lying near the center of the cell, as shown in Pl. 5, fig. 6. Sometimes we find the cell boundaries apparently cutting through a nucleus, as we see them doing in a few instances in Pl. 5, fig. 7. This is merely a condition due to the over-lapping of one cell by another, as was shown by Schmidt in the case of the frog. A projection of the relation of the nucleus to the boundary lines is shown in Pl. 5, fig. 8.

To demonstrate the presence of cilia the animals were killed by pithing; the lung was then removed and cut open along both the artery and the vein. The cilia were seen to better advantage at the edges of the preparation than on the surface. Ciliated

epithelial cells were found over both the artery and vein, down to the apex of the lung, while a few were also found between them. This is not the case in the newt according to Stirling, the ciliated epithelium being found only over the pulmonary vein and its principal branches, while a plexus of capillaries lies over the artery. Williams, in contradistinction to Stirling, figures the ciliated epithelium over both the artery and vein of the newt. In *Necturus* I found a plexus of capillaries, as well as the ciliated epithelium over both artery and vein.

THE ELASTIC FIBERS.

The elastic fibers of the lung of *Necturus* form an exceedingly complex network, as shown in Pl. 6, fig. 9. The fibers are of two types, the coarser ones being nearer the surface, and forming wider meshes than the finer and deeper ones. They also run more generally in a direction parallel to the long axis of the lung. The meshes of the fine fibers are exceedingly intricate, especially around the blood-vessels. Stirling describes the elastic fibers as forming a layer lying between the endothelium and the layer of smooth muscle, but this cannot be said of the lung of *Necturus*. Fibers are found scattered throughout the walls of the lungs. Pl. 7, figs. 11, 12, show longitudinal and cross sections of the lung of *Necturus* taken near blood-vessels which show the fibers as dots or lines, according as they are cut transversely or more or less longitudinally.

THE MUSCLE FIBERS.

The muscle fibers are of the involuntary type and run principally in a circular direction, thus forming a tubular foundation for the lung. The nuclei of the fibers are shown in Pl. 7, figs. 11, 12; Pl. 8, figs. 13, 14. At the tip of the lung the fibers form an intricate network, running in all directions.

Stirling mentions a difference in position of the vein and artery with reference to the layer of muscle fibers, the artery lying internal to this layer, while the vein lies externally to it.

This does not hold true for the lung of *Necturus*, since both the artery and the vein lie superficially, the greater part of the muscle fibers lying internal to them. Pl. 8, figs. 11, 12, shows the relation between the blood-vessels and the muscular fibers. It will be noted that the relation is the same in both the artery and vein.

THE NERVE FIBERS.

The distribution of the nerves in the lung is shown in Pl. 6, fig. 10, and Pl. 8, fig. 15. Contrary to the usual opinion, we do not find the main branches along the blood-vessels, but rather between them. To be sure, there are nerve trunks lying over the blood-vessels, yet they are not so large as those forming the elongated meshwork between them. The anastomoses between the trunks are quite numerous, increasing as they diminish in size until we come down to the ultimate fibers.

This distribution is contrary to that found by Stirling in the lung of the newt. He says:

> "The nerves enter the lung in three or four main strands at its base. These strands are of unequal thickness, i. e., a varying number of nerve-fibers enter into their composition. At once they proceed towards the pulmonary vein, which they follow very closely in their distribution. They form a plexus along the course of the vein. Only a few non-medullated nerve-fibers pass on to the pulmonary artery. The nerve-strands lie outside the muscular coat, and as they pass onwards in the pulmonary walls they give off branches right and left. A large number of multipolar nerve-cells exist in the course of the nerve-strands, and they are especially numerous where a branch is given off."

Both medullated and non-medullated fibers are found in the main trunks. From this main network we get a second network with fewer fibers in a branch, but still containing both kinds of fibers. From this secondary network we have a fine network of non-medullated fibers given off which breaks up into the ultimate fibrils. These last I did not try to follow out to their endings. Along the course of the fibers, as well as the trunks, nerve-cells are present, and my observations in *Necturus* coin-

cide, except in the connections between the fibers and cells which I did not investigate, with those of Stirling in the newt. He says:

"A large number of nerve cells are found along the whole course of these mixed nerve strands and occur singly or in groups, and are usually most numerous where branches are given off.

"They are not confined to the main trunks, however, but recur singly or in small groups in the larger nerve branches. Sometimes the cells lie singly between the sheath of the nerve and the nerve fibers, whilst others lie crushed up as it were between the nerve fibers. As already remarked, they are most numerous where a nerve twig is given off from the main mixed strand. In these small aggregations of nerve cells it is easy to trace the course of a medullated fiber sweeping clear through the mass, and forming no connections with the cells, whilst, occasionally, one may see a connection between a nerve cell process and one of the non-medullated fibers. The shape of the nerve cells seems to vary considerably; some appear to be bipolar, whilst others are polygonal and have several processes, one or more of which may become continuous with a non-medullated fiber. Each cell contains a relatively large nucleus usually placed eccentrically, and the body of the cell may or may not be enclosed in a capsule. Other nucleated masses of protoplasm devoid of processes lie amongst the nerve fibers, and it is not clear what is their exact nature. Perhaps they may represent developing nerve cells."

TECHNIQUE.

The specimens were killed by chloroform, although some were used that had been dead for a few hours, and those used for the work on the epithelium were killed by pithing. The lungs were removed by opening the body cavity at the left side of the median ventral line and then cutting through the ventral mesentery, which allowed me to throw back the flap of the body-wall, thus exposing the whole of the viscera to view. The lungs were carefully blown up with a syringe introduced through the mouth, into the glottis. This made the lungs very prominent and it was a comparatively simple matter to cut through the fold of peritoneum, which attaches the lung to the body-wall. Care was exercised, in handling the lungs, not to puncture them, as

their walls were very thin. Threads were passed around each of the lungs near their union at the anterior end of the liver and then they were cut off and at once put into the fixing fluid or into the stain as the procedure necessitated. As the lung was kept distended by this method it allowed me to handle it without touching the surfaces and at the same time produced a uniformly distended and perfectly smooth surface. On account of the great amount of blood present in the lungs, it was found necessary to remove it in some manner so as to be able to see the finer structures, especially with a high power. This was done by washing out the blood with normal salt solution, injecting it into the main artery.

For the study of the peritoneal covering and of the epithelium of the lung, the usual methods with nitrate of silver were used. An interesting point was brought out while investigating the epithelium, viz., that while on all ordinary serous membranes Dekhuysen's method had given the most satisfactory results, in *Necturus* it proved to be exceedingly unsatisfactory. This was probably due to some action of the nitric acid on the peculiar viscid secretion which covered the lungs; for, when after many failures the simple aqueous solution was used, each cell appeared bounded by clear and sharply defined lines.

For elastic fibers Hoehl's modification of Unna's orcein stain for the skin was used; it gave uniform and very satisfactory results. For the nerves methylene blue was use with varying success.

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Plate 3.

Description of Plate 3.

Lung of *Necturus maculatus.*

Fig. 1. Epithelium between the large blood-vessels. × 165.

Fig. 2. Epithelium near the large blood-vessels and end of lung. × 165.

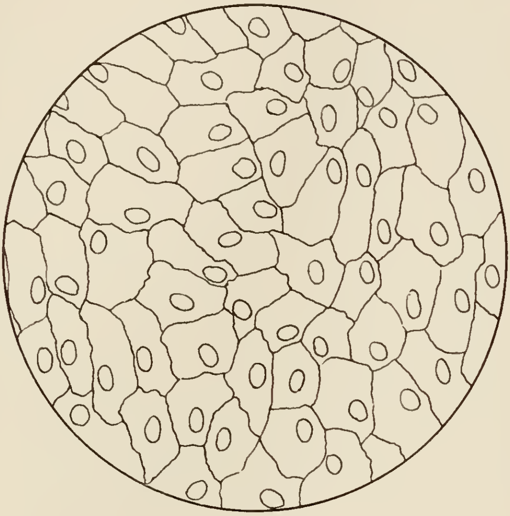


fig. 1.

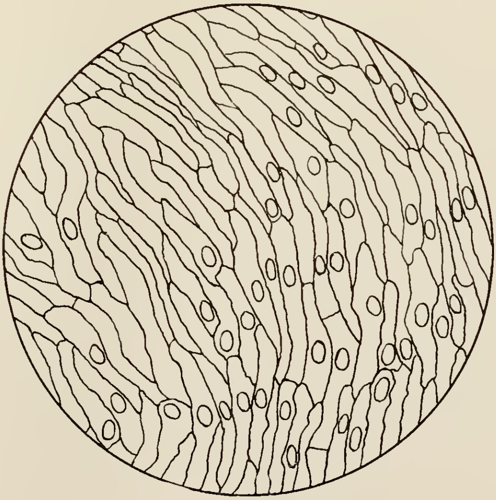


fig. 2.

Plate 4.

Description of Plate 4.

Lung of *Necturus maculatus.*

Fig. 3. Epithelium over the blood-vessels and lymphatics. × 165.

Fig. 4. Epithelium within the lung showing outline of cells and islands. × 250.

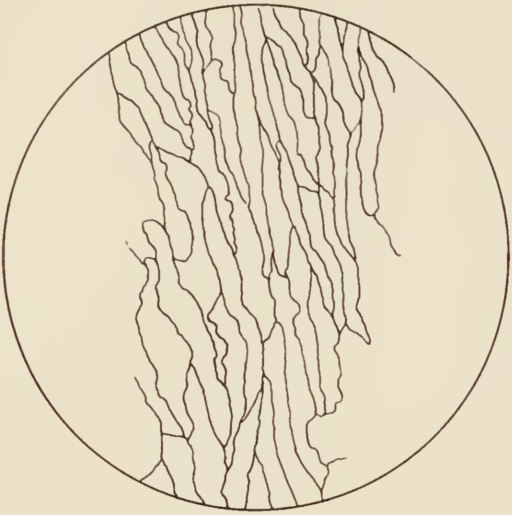


fig. 3.

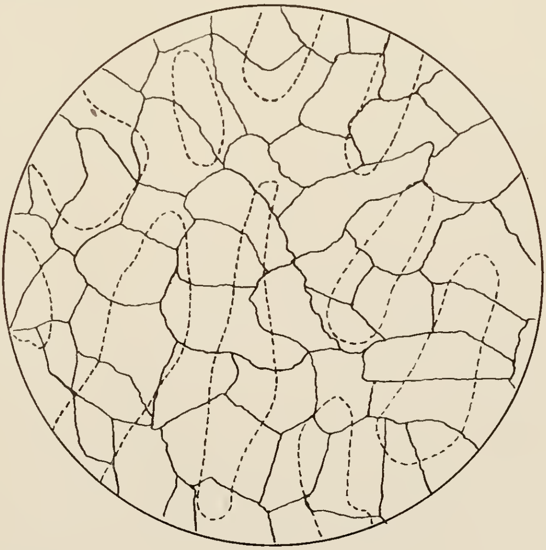


fig. 4.

Plate 5.

Description of Plate 5.

Lung of *Necturus maculatus*.

Fig. 5. Relation of nuclei and protoplasm to group of cells in an island. $\times$ 350.

Fig. 6. A single cell forming an island. $\times$ 250.

Fig. 7. Cell boundaries crossing over nuclei of neighboring cells. $\times$ 250.

Fig. 8. Projection drawing of two cells from figure 7, showing relation of cell boundaries to nucleus and to two underlying capillaries. $\times$ 250.

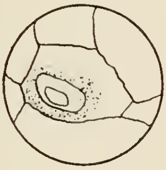


fig 6

fig.7

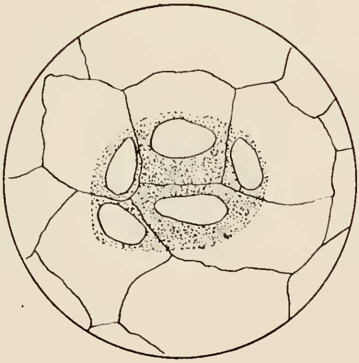


fig. 5.

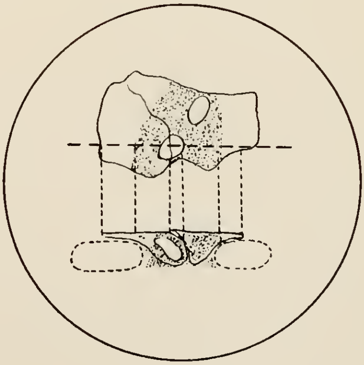


fig. 8.

PLATE 6.

Description of Plate 6.

Lung of *Necturus maculatus.*

Fig. 9. Surface view of elastic fibers over the pulmonary artery. Orcein staining. × 400.

Fig. 10. The finer network of nerve fibers, showing medullated and non-medullated fibers and nerve cells. Methylene blue. × 75.

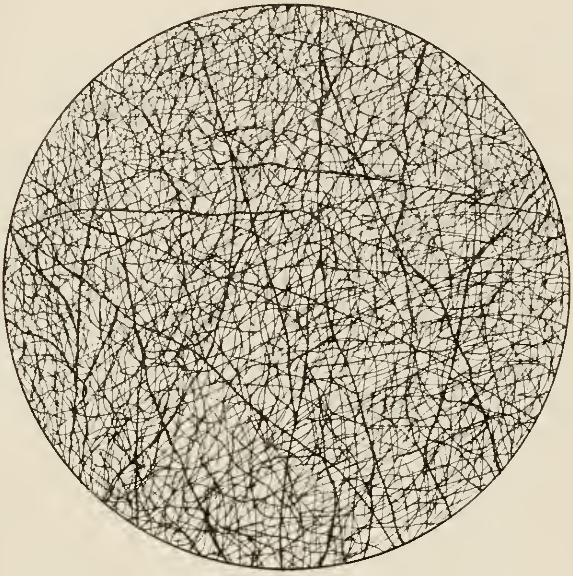


fig. 9.

fig. 10.

Plate 7.

Description of Plate 7.

Lung of *Necturus maculatus.*

Fig. 11. Elastic fibers and muscle nuclei in a longitudinal section of lung. Orcein staining. $\times$ 400.

Fig. 12. A transection of lung. Same preparation as figure 11. $\times$ 400.

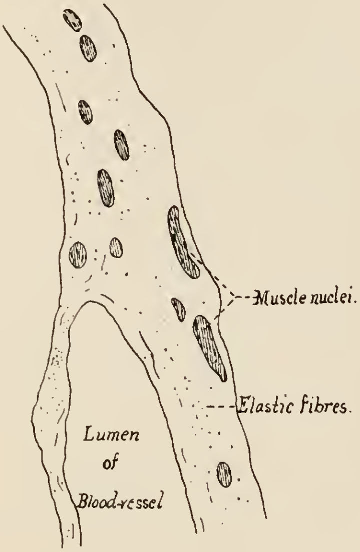

Muscle nuclei.
Elastic fibres.
Lumen
of
Blood-vessel

fig. 11.

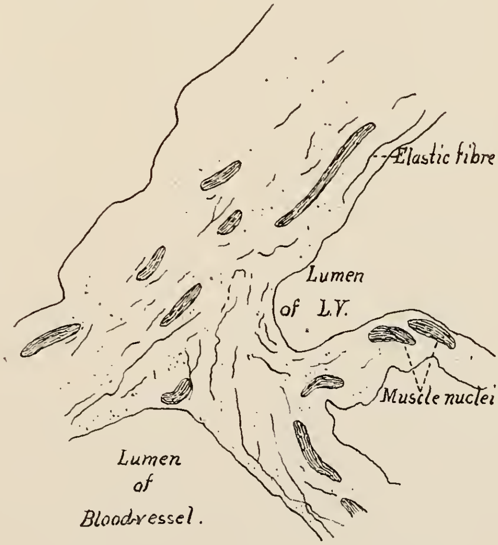

Elastic fibre
Lumen
of L.V.
Muscle nuclei
Lumen
of
Blood-vessel.

fig. 12.

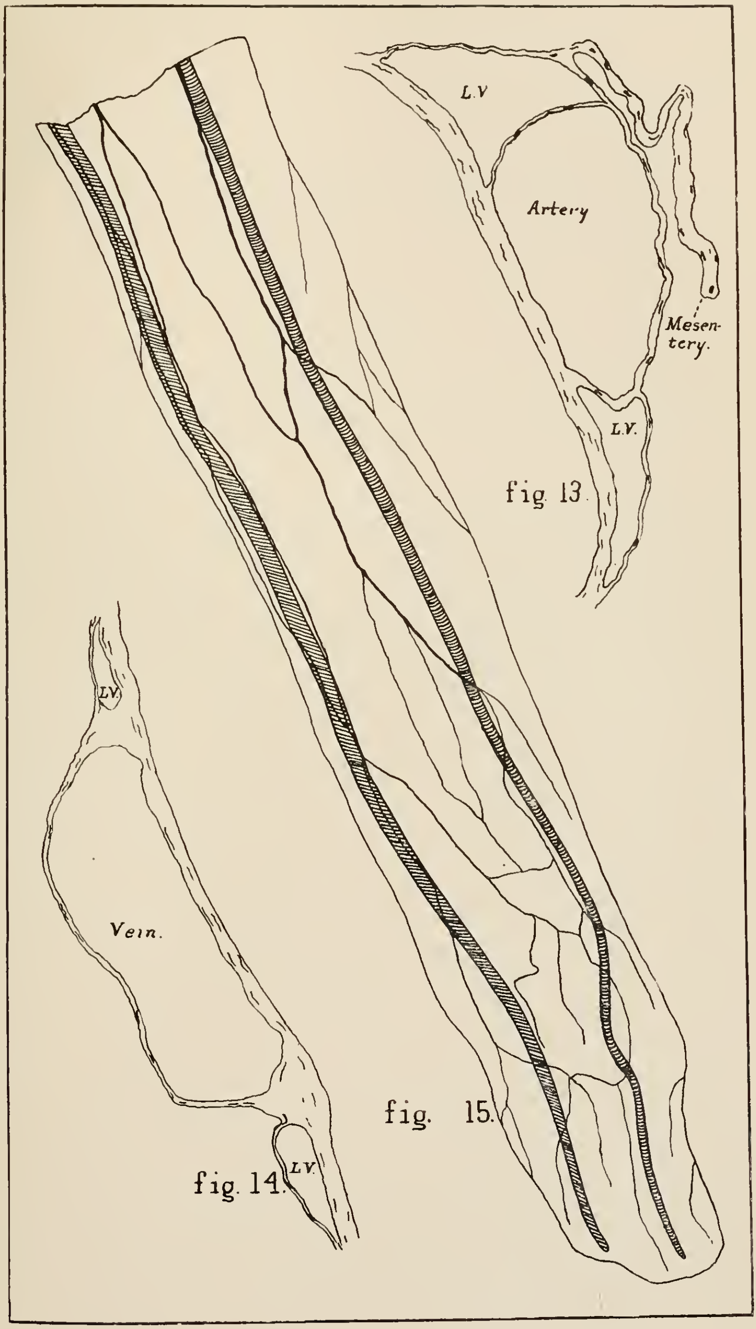
PLATE 8.

Description of Plate 8.

Lung of *Necturus maculatus*.

Figs. 13 and 14. These sections show the relative thickness of the layer of muscle fibers, both internal and external to the artery and vein. Note the superficial situation of both vessels. × 40.

Fig. 15. The distribution of the main nerve trunks. × 3.


L.V
Artery
Mesentery.
L.V.
fig. 13.
L.V.
Vein.
L.V.
fig. 14.
fig. 15.

THE VASCULAR SYSTEM OF *Necturus maculatus*.

THE ARTERIES.

For convenience of description the ventral aorta and its branches will be considered with the arteries although it contains venous blood.

From both sides of the anterior extremity of the TRUNCUS ARTERIOSUS, Tr. Pl. 9, and fig. 1, Pl. 10, arise two vessels, a smaller anterior and a larger posterior. For a distance of about 5 mm they appear as a single vessel, being separated merely by a septum. The anterior, THE FIRST AFFERENT BRANCHIAL ARTERY, A. B.–1, Pl. 9, and fig. 1, Pl. 10, runs out almost at right angles to the truncus, to the first branchial cartilage, along the postero-ventral edge of which it continues to the gill. In the gill it runs along its ventral edge, giving rise to numerous fine branches which subdivide and form a loop, with a capillary network between, in each tuft. The posterior larger vessel also runs out nearly at a right angle to the truncus parallel to the first afferent vessel, then makes a sharp turn caudal, continuing between the two posterior branchial cartilages. About 5 mm posterior to the turn it divides into two branches, the SECOND and THIRD AFFERENT BRANCHIAL ARTERIES, A. B.–II., A. B. –III., Pl. 9, and fig. 1, Pl. 10. Each runs along the corresponding branchial cartilage into the gill, where it breaks up in a manner similar to the first.

The EFFERENT BRANCHIAL ARTERIES arise by numerous radicles formed by the capillaries of the gill tufts uniting along the dorsal edge of the gill to form a common vessel. Just at the point where the FIRST and SECOND EFFERENT BRANCHIAL AR-

teries, E. B.–I., E. B.–II., Pl. 9, and fig. 1, Pl. 10, leave the gill, each gives off a branch which crosses the proximal edge of the gill. The branch arising from the first efferent artery forms the External Carotid, E. C., Pl. 9, and fig. 1, Pl. 10, while the branch arising from the second efferent artery goes to the second afferent branchial artery, E. B. a., Pl. 9, and fig. 1, Pl. 10. The Second and Third Efferent Branchial Arteries unite at the posterior edge of the second branchial cartilage. The vessel thus formed, C. V., Pl. 9, and fig. 1, Pl. 10, and the first efferent branchial artery are united by a short vessel, A. B., Pl. 9, and fig. 1, Pl. 10, as soon as they enter the buccal cavity, along the dorsal side of which they run. The first efferent branchial artery, after giving off the above connecting branch, A. B., makes a bend and runs directly cephalad as the Internal Carotid, I. C., Pl. 9, and fig. 1, Pl. 10. The vessel formed by the union of the second and third efferent arteries, after giving off the pulmonary artery, P., Pl. 9, and fig. 1, Pl. 10, is continued as one of the Aortic Roots, R. A., Pl. 9, and fig. 1, Pl. 10.

The Internal Carotid, I. C., Pl. 9, arises from the first efferent branchial artery at the point where the anastomosing branch is given off to the conjoined second and third efferent arteries. It runs along the medio-ventral edge of the masseter muscle and the ventral surface of the parasphenoid bone making two convex and one concave turn towards the outside. It pierces the parasphenoid opposite the first branchial cartilage, continues along its dorsal surface for a short distance, about 8 mm, pierces it a second time, and, running along its ventral surface, ends in the premaxilla.

At a point just anterior to the first gill the internal carotid gives off several branches. They pierce the parasphenoid bone and emerge anterior to the pterygoid. The most posterior of these branches, the Internal Inferior Maxillary, I. I. M., Pl. 9, runs under the tympanicum to the ramus of the lower jaw, where it gives off a branch to the digastric and mylohyoid muscles, a branch to the branchial cartilages, and then continues along the internal side of the ramus of the lower jaw, giving off a

branch to the lip. The second branch, the External Inferior Maxillary, E. I. M., Pl. 9, runs along the anterior side of the pterygoid and is distributed to the outer surface of the ramus of the lower jaw. A third branch, the Orbito-Nasal, O. N., Pl. 9, runs along the lower border of the temporal muscle between it and the masseter muscle; passing around the dorso-median side of the eye it gives off branches to the muscles of the orbit, and then goes to the nasal fossa, where it divides into two branches, one on each side. Two small branches pass to the temporal muscle. Another branch of considerable size is the Ophthalmic, Oph., Pl. 9, which arises in common with the other branches of the internal carotid and runs nearly parallel with its distal part to be distributed to the eye. Sometimes the ophthalmic sends branches to the nasal capsule.

Just as the internal carotid pierces the parasphenoid it gives off a branch at nearly a right angle, the Cerebral Carotid, C. C., Pl. 9, which passes to the ventral side of the brain where it divides into an anterior and a posterior branch. The anterior continues along the ventral surface of the cerebral hemisphere of the same side, ending in a number of fine branches. The posterior branch runs diagonally candad and unites with its fellow from the other side to form the Basilar Artery, Bs., Pl. 9, and then runs along the ventral side of the medulla, giving off branches at right angles to its course. The two largest of these, Au., Pl. 9, pass one on either side to the ear.

The Vertebral Artery, Vert., Pl. 9, arises from the root of the aorta, runs cephalad to the parasphenoid, where it divides into two branches, one running towards the median plane, the other away from the median plane. The latter again divides into three small branches, a posterior and a lateral branch going to the roof of the mouth and an anterior branch to the side of the medulla. The former branch runs along the spinal column dorsal to the lateral processes.

The Pulmonary Artery, P., Pl. 9, and fig. 1, Pl. 10, arises from the third efferent branchial artery between the point where the second efferent artery joins it and where the anastomosing branch from the first efferent enters. It gives off a few small

branches to the shoulder, one, Ps., Pl. 9, going to the muscles of the scapula and one, Pb., Pl. 9, to the cucullaris muscle; from here it continues along the ventral surface of the buccal cavity giving off one or two branches to it, a branch to the œsophagus, P. oe., Pl. 9, and then proceeds along the dorsal side of the lung giving off short branches at right angles to its course.

The External Carotid Artery, E. C., Pl. 9, and fig. 1, Pl. 10, arises from the first efferent branchial; it also receives a number of small anastomosing branches from the first afferent branchial artery which accompany it as far as the sternohyoid muscle, which it supplies with a branch. From here it continues cephalad along the medio-dorsal surface of the digastric muscle closely applied to the hyoid arch, giving off a branch to the geniohyoid and mylohyoid muscles and then anastomoses with its fellow from the other side at the insertion of the digastric muscle into the lower jaw.

The Dorsal Aorta, A. O., Pl. 9, is formed by the union of the two aortic roots and runs along the ventral surface of the vertebral column. It is the main trunk of the arterial system and gives off numerous branches as it passes backwards through the abdominal cavity.

The Subclavian, Sbc., Pl. 9, and fig. 2, Pl. 10, arises from the aorta about 5 mm posterior to the union of the aortic roots, runs outward between the external oblique and erector spinae muscles, makes a slight turn dorsad and continues along the ventral surface of the scapula. Near the glenoid fossa the continuation of the subclavian, now called the Axillary Artery, gives off a branch which may be called the Thyroid Axis, T. A., fig. 2, Pl. 10. This almost immediately gives off a branch, Ta., fig. 2, Pl. 10, which enters the anconeus muscle and breaks up into three smaller branches. The most anterior, T. a. c., fig. 2, Pl. 10, passes between the anconeus and the humero antibrachialis inferior muscles across the head of the ulna, along the surface of the extensor digitorum communis to the first digit. The middle branch, T. a. b., fig. 2, Pl. 10, runs along between the head of the radius and the ulna to the last digit. The smallest and most posterior branch, T. a. a., fig. 2, Pl. 10, goes to the ancon-

eus. The main portion of the thyroid axis, Tb., fig. 2, Pl. 10, runs across the head of the humerus into the procoro humeralis giving off several branches which supply this muscle, the cucullaris and the antibrachialis inferior. The latissimus dorsi may receive its blood supply from this artery or from T. a. a.

The Cutaneous Artery, Cu., Pl. 9, and fig. 2, Pl. 10, arises from the axillary and runs across the ventral surface of the coracoid; a little posterior to the glenoid fossa it gives off two branches, one, Ca., fig. 2, Pl. 10, accompanies the brachialis around the upper part of the shaft of the humerus and continues between the coraco branchialis longus and the humero antibrachialis inferior. Sometimes this branch arises directly from the axillary artery. The other branch, Cu. a., fig. 2, Pl. 10, of the cutaneous goes to the pectoral muscles, while the cutaneous itself, Cu., Pl. 9, passing candad, pierces the body wall and runs along its inner surface external to the linea alba anastomosing with the intercostals and the epigastric.

The continuation of the axillary, the Brachial Artery, Br., fig. 2, Pl. 10, passes around the upper part of the shaft of the humerus to its anterior side, running between the extensor carpi radialis and ulnaris muscles; passing between the radius and ulna it crosses to the outside of the forearm ventral to the extensor digitorum communis. Just proximal to the carpus the brachial gives off four branches; one, Br. a., fig. 2, Pl. 10, to the flexor carpi radialis, which is continued to the outside of the first digit; one, Br. b., fig. 2, Pl. 10, to the flexor carpi ulnaris, which continues to the fourth digit; one to the flexor digitorum communis and one to the extensor carpi ulnaris. The brachial is continued as the Cubital Artery, which runs between the cartilages of the carpus to the dorsal side of the hand, where it breaks up into three branches. The first of these goes to the adjacent sides of the first and second digits, the second goes to the adjacent sides of the second and third digits, the third goes to the adjacent sides of the third and fourth digits.

The next large artery arising from the dorsal aorta is the Gastric, G., Pl. 9. It runs candad to the stomach on which, a little anterior to the center, it divides into two branches, one

going to the right side, the other to the left. Both branches subdivide to supply this organ and in addition to this the left branch gives off one or two branches to the spleen, Sp., Pl. 9.

The COELIACO-MESENTERIC, Coe. M., Pl. 9, arises from the dorsal aorta near the center of the abdominal cavity and runs out at right angles to the aorta through the pancreas, where it divides into three main branches. The first of these branches runs cephalad through the anterior lobe of the pancreas dividing into two smaller branches, one containing anterior, as the SPLENIC, Sp′., Pl. 9, to supply the spleen, the other runs out at nearly a right-angle to the stomach; this is the CORONARY, Cor., Pl. 9. The second branch is the HEPATIC, Hp., Pl. 9, which supplies the liver and the gall bladder. The third branch goes to the intestine.

The INFERIOR MESENTERIC ARTERIES, I. M., Pl. 9, sometimes as many as twenty in number, arise from the aorta at varying intervals and run to the intestine, dividing, and as a rule, anastomosing before they reach it, forming a sort of discontinuous vessel along the attached border of the intestine. From this, short semi-circular arteries arise which pass to the wall of the intestine.

In the male, nine to eleven SPERMATIC ARTERIES, Spr., Pl. 9. arise on each side from the dorsal aorta and enter the testis. In the female numerous minute arteries go to the fallopian tubes and ovaries. The kidneys receive also a variable number of RENAL ARTERIES, K., Pl. 9, which arise from the aorta.

Throughout the entire course of the aorta short vessels arise at regular intervals from its dorsal side, corresponding in number to the vertebrae; these run dorsad at right angles to the aorta and divide into two branches, one for each side. Each branch runs outwards between the oblique muscles, to which they give off small branches, and at their distal end anastomose with the cutaneous and epigastric. The name INTERCOSTAL ARTERIES, Icls., Pl. 9, may be given to these vessels. Between the intercostals, dorsal to the lateral processes of the vertebrae, lie anastomosing branches, Anas., Pl. 9, which are continuous with the vertebral.

The Iliac Artery, Il., Pl. 9, and fig. 3, Pl. 10, arises from the aorta just anterior to the posterior extremity. It runs outward and backward along the inner surface of the body wall until it reaches a point directly above the ischium, where it divides into three main branches. The most anterior, the Epigastric Artery, Epi., Pl. 9, and fig. 3, Pl. 10, runs cephalad and anastomoses with the cutaneous; it gives off a small branch, Epi. R., fig. 3, Pl. 10, to the rectus femoris and one to the body wall, Epi. B., fig. 3, Pl. 10. The middle and main branch is the Femoral Artery, Fr., Pl. 9, and fig. 3, Pl. 10, which directly continues the iliac. It crosses the ventral surface of the ischium and at its posterior border gives off a branch which immediately divides into three small branches. The most anterior of these, Fr. c., fig. 3, Pl. 10, runs around the head of the femur and continues between the rectus femoris and the sartorius; it breaks up in the flexor digitorum communis and sends a branch to the first digit. The second of these three branches, Fr. b., fig. 3, Pl. 10, runs under the rectus femoris and continues beneath the skin of the fore leg to the last digit. The third and most posterior branch, Fr. a., fig. 3, Pl. 10, goes to the sacro-plantaris muscle.

The femoral itself continues along the postero-dorsal surface of the upper half of the gracilis, crosses the femur diagonally to its anterior surface and continues between the gracilis and sartorius muscles. On the inner surface of the fore leg, between the tibia and fibula, it gives off several branches, one to the flexor tarsi tibialis, C. a., fig. 3, Pl. 10, which is continued to the first digit, one to the flexor tarsi fibularis, which is continued to the last digit, C. b., fig. 3, Pl. 10, one to the flexor and one to the extensor digitorum communis. The femoral then runs between the cartilages of the tarsus to the dorsal side of the foot, where it breaks up into three branches. The first of these goes to the adjacent sides of the first and second digits, the second to the adjacent sides of the second and third digits, and the third goes to the adjacent sides of the third and fourth digits.

The third branch of the iliac, the Vesical Artery, Vs., Pl. 9, Vsc., fig. 3, Pl. 10, arises just before the iliac pierces the body

wall. It runs along the ventral surface of the body wall to the bladder, where it, together with its fellow from the opposite side, gives off three branches to that organ. One of these branches sends a short twig to the posterior part of the intestine. The vesical then proceeds to the cloaca, Vs. Gl., fig. 3, Pl. 10, where it breaks up. At about the center of the vesical artery two branches are given off; one, Vs. I., fig. 3, Pl. 10, passes cephalad to the muscles on the ventral surface of the ilium, the other runs caudad to the cloaca, Vs. an., fig. 3, Pl. 10.

Just posterior to the anal gland the aorta enters the haemal arches of the caudal vertebrae and continues to their end as the CAUDAL AORTA, Ca. A., Pl. 9, giving off branches to the muscles of the tail. At the anal gland the aorta gives off two branches, one, Gl., Pl. 9, on each side to the anal gland, and one, M., Pl. 9, to the muscles of the body wall.

THE VEINS.

The venous system of *Necturus* is exceedingly interesting, showing as it does points of resemblance to that of the Dipnoi on the one hand, and the higher Amphibia on the other. I would call special attention to the sinus between the postcaval vein and the *Sinus Venosus;* the communication between the posterior cardinals and the postcaval; the anastomosis between the posterior cardinals and the renal portal,—a condition which, it seems to me, is intermediate between that of *Protopterus annectens* and *Salamandra maculosa.* The constant presence of the anastomoses between the two sets of gastric veins is also quite conspicuous.

For convenience the venous system will be described under three heads:

1. RENAL PORTAL.
2. HEPATIC PORTAL.
3. SYSTEMIC VEINS.

In each case the description will be begun with the distal vessels and followed towards the heart.

RENAL PORTAL.

The Renal Portal system is formed by the bifurcation of the CAUDAL VEIN, C., Pl. 11. This arises at the end of the tail and runs in the haemal arches of the caudal vertebrae ventral to the caudal aorta. Just posterior to the cloaca the caudal vein bifurcates, each branch passing along the outer side of the corresponding kidney and giving off numerous vessels, VENAE ADVEHENTES, V. Adv., Pl. 11, into these organs. Into the renal portal open the veins from the posterior extremity.

Each of the four digits of the foot has two veins, one on either side; these two veins usually unite and form short and somewhat larger vessels, which join to form a still larger trunk on the dorsum of the foot. This latter vessel runs across the distal end of the extensor digitorum muscles near the proximal end of the digits. This transverse vein receives also a number of small vessels which come from the tarsus. From the outside of the foot this vein is continued towards the body as the POSTERIOR TIBIAL VEIN, Fbl., Pl. 11, which courses upwards, and near the knee joint it bends gradually and passes over the knee to the flexor surface of the leg. Above the knee it is continued as the FEMORAL VEIN (Sciatic?), Sci., Pl. 11; this passes over the hip joint and unites with the PELVIC VEIN, Pel., Pl. 11, about 10 mm from the point of union of the latter and the renal portal.

I am aware that this differs from the usual description of the veins in Amphibia. Most authors describe the femoral as dividing into two branches, a pelvic and iliac; but no such division could be made out in any of the specimens studied. The angle of union between the femoral and pelvic and the size of the pelvic precludes, it seems to me, such description.

Just below the knee the posterior tibial receives a branch which comes from the median side of the leg. Midway between the knee and the hip the femoral receives a considerable branch from the ventral side of the thigh and from about the knee joint. Just before the femoral joins the pelvic vein it receives two small

branches; one from about the cloaca, the other from the anterior region of the thigh.

The two renal portals are connected by the Pelvic Veins, Pel., Pl. 11, which unite in the mid-ventral line of the body to form the Abdominal Vein, Abd., Pl. 11. The Pelvic Veins, Pel., Pl. 11, unite with the renal portal near the middle of the kidney. From this point of union each pelvic vein runs along the inner side of the body wall until it is joined by the femoral; it also receives a number of small branches from the muscles of the back. After the femoral has joined it, the pelvic vein runs anteriorly towards the point of union with its fellow from the opposite side, where, as already mentioned, they form the Abdominal Vein, Abd., Pl. 11.

From its place of origin the abdominal vein runs through the ventral mesentery and the posterior part of the liver to join the hepatic portal. The abdominal vein receives close to the union of the two pelvic veins a small branch which comes from the anal gland and cloaca, A., Pl. 11. In its course through the ventral mesentery it receives the Cystic Veins, Cys., Pl. 11; these are usually two in number. It also receives several small veins from the body walls. The abdominal vein enters the liver at the fissure in its posterior border. In its course through the liver it receives branches from the liver substance; the largest of these comes from the left side of the liver.

THE HEPATIC PORTAL.

The Hepatic Portal, H. P., Pl. 11, is formed on the dorsal surface of the liver by the union of the mesenteric, gastric, splenic and abdominal veins. The Mesenteric Vein, Mes., Pl. 11, arises by from twelve to fifteen branches from the whole length of the intestine; occasionally at its distal end it receives a few small branches from about the cloaca. For the greater part of its course it is situated in the mesentery; the anterior portion, however, passes through the pancreas in order that it may reach the dorsal side of the liver. The anterior three branches from the intestine to the mesenteric vein are larger

than the other branches and do not join it until after it has entered the pancreas.

The gastric vein arises from the posterior third of the stomach by two branches; one on the dorsal and one on the ventral side. These branches unite at the pylorus and form the GASTRIC VEIN, Gv., Pl. 11, which immediately enters that lobe of the pancreas which is closely applied to the intestine just posterior to the stomach. As it passes through the pancreas it receives small branches from the pancreas itself and the adjacent part of the intestine; it continues in the pancreas until it joins the mesenteric vein on the dorsal surface of the liver.

About 6 mm anterior to the junction of the mesenteric and gastric, the trunk thus formed is joined by the SPLENIC VEIN, Sp., Pl. 11. This vessel arises at the anterior end of the spleen, and in its course along the ventral surface of that organ receives many small branches from it. It is also joined by from two to four veins which bring blood from the dorsal portion of the anterior two-thirds of the stomach. The more anterior of these veins are smaller than those which come from the central region of the stomach. In two specimens a large vein was found running dorsally from the spleen, and, passing to the median side of the left lung, it joined the left posterior cardinal.

Just beyond the enlargement formed by the union of the mesenteric, gastric and splenic veins the ABDOMINAL VEIN, Abd., Pl. 11, usually joins the hepatic portal; in other cases it empties into the enlargement itself.

The HEPATIC PORTAL, H. P., Pl. 11, after being formed in the manner already described, runs anteriorly at the bottom of the fissure on the dorsal side of the liver. It becomes smaller and smaller, on account of the numerous branches which it gives off, and finally, at the anterior end of the liver, breaks up into small branches. About 20 mm from the anterior end of the liver a variable number of veins, two to four in number, coming from the antero-ventral portion of the stomach, G., Pl. 11, join the hepatic portal. The most posterior of these veins is the largest, and is mainly formed by a branch which can be traced posteriorly along the ventral side of the stomach to form an

anastomosis with the ventral branch of the gastric vein, Gv., Pl. 11.

From the median line of the abdominal wall the hepatic portal receives from twelve to fifteen veins. Each of these veins is formed by two branches which, coming from either side in the septa of the abdominal muscles, unite at the mid-ventral line. These veins run from the body wall to the liver in the ventral mesentery, in which they often form an open network, each vessel being joined by a transverse branch, or they may unite so that not more than seven or eight veins enter the liver. Within the liver they join, as has been said, the branches of the hepatic portal.

All the blood which is brought to the liver by the hepatic portal and abdominal veins is collected by the Hepatic Veins, H., Pl. 11, which empty into the postcaval vein at different points along its course through the liver. The hepatic veins vary greatly in size and have no fixed point of entrance into the postcaval. Two of the hepatic veins are much larger than the others and have a fairly constant point of union with the postcaval. The larger of these two veins arises at the posterior end of the liver and joins the postcaval near the center of the liver. The other is not as constant in its course or place of origin; in the majority of the specimens examined it took its origin near the posterior border of the liver and ran along the left margin of the liver, receiving many small branches, and finally united with the postcaval at the anterior end of the liver. The first of these two hepatic veins is shown in Pl. 11, but for the sake of clearness the last is omitted.

SYSTEMIC VEINS.

The Posterior Vena Cava, or Postcaval Vein, P. C., Pl. 11, is the largest vein in the body; it runs anteriorly between the kidneys receiving through the Venae Reheventes,' V. Rev., Pl. 11, the blood which has been brought to these organs by the venae advehentes, and a few veins from the muscles of the back. From the kidneys it is continued just ventral to the aorta until it is from 20 to 50 mm anterior to the posterior

border of the liver; it then bends ventrally from the aorta and enters the liver somewhat to the left of the median line. In the liver it continues anteriorly until it reaches its anterior margin where it divides into the Hepatic Sinus, H. S., Pl. 11, which, after being joined by the Ducts of Cuvier, D. C., Pl. 11, empties into the Sinus Venosus.

In the female the posterior vena cava receives on each side as it passes between the ovaries from fourteen to twenty Ovarian Veins, O., Pl. 11. The number differs not only in different specimens, but also on the different sides of the same specimens. These veins are small and very tortuous. Usually two or three form a small group and unite just before they enter the postcaval. They vary in length as well as in size; those from the center of the ovaries are about 10 mm long, while those from the ends are not more than 5 mm in length. The adjacent groups of veins are connected with each other by small cross branches near the ovaries.

In the male five, rarely four or six large, and several small, Spermatic Veins run from each testis into the postcaval as it passes between them.

On the convex side of the bend where the posterior vena cava leaves the dorsal wall of the body cavity to enter the liver, it is joined by a vessel which branches like a Y, and connects it with each of the posterior cardinal veins, Y., Pl. 11.

The Posterior Cardinal Veins, P. C., Pl. 11, arise near the central part of the body on each side of the aorta. They run anteriorly until near the Duct of Cuvier; here they bend laterally and empty into these vessels at their distal end. At their caudal end the posterior cardinals are connected with the renal portal by means of muscular branches which come from the back. Each muscular vessel in this region of the back, as soon as it penetrates the body wall divides into two branches, one of which passes anteriorly, the other posteriorly. These branches anastomose with each other and eventually with the posterior cardinal in front and the renal portal behind. The letters R. P., in Plate 11 are opposite the branches which form the anastomosis. This connection between the posterior cardi-

nals and the renal portal is more marked in the female than in the male. Besides the muscular vessels taking part in the anastomosis there are others which join the posterior cardinal along nearly its entire length; these veins are about 6 mm apart and come from between the vertebrae. Each posterior cardinal communicates with the posterior vena cava on the convex side of the bend where it leaves the dorsal body wall. Sometimes the communicating vessels are separate and enter the postcaval near together. More often the veins from the posterior cardinals unite before they enter the postcaval as already described, V., Pl. 11.

The FALLOPIAN VEINS, F., Pl. 11, are small vessels which run in a wavy course along the ventral side of the anterior part of each fallopian tube. At the anterior end of each tube the vein joins the posterior cardinal of that side. Besides this principal vein there are numerous small vessels which pass from the walls of the fallopian tubes to the posterior cardinal veins, Z., Pl. 11. Opening into the fallopian vein, near its junction with the posterior cardinal, are two or more small branches which come from about the ostium abdominale of the oviducts.

Taking up now the veins that return the blood from the head, it will be seen that there are three: the internal jugular, the external jugular, and the lingual, on each side.

The INTERNAL JUGULAR, Ji., Pl. 11, is formed principally by the union of two veins; one of these comes from the roof of the mouth, the other from the brain case, the upper part of the spinal column and the dorsal wall of the pharynx. From the place of union of these two branches, the internal jugular runs posteriorly to unite with the external jugular about 7 mm anterior to the junction of latter with the Duct of Cuvier.

The EXTERNAL JUGULAR, Je., Pl. 11, receives branches from the external parts of the head and from the ventral wall of the mouth. It is formed for the most part by the union of two veins. One of these, the NASO-ORBITAL VEIN, N. Or., Pl. 11, runs across the masseter muscle, receiving branches from the antero-dorsal part of the head and from the eye. The other

of these branches, the Submaxillary Vein, Sbm., Pl. 11, is formed by branches from the antero-ventral wall of the oral cavity and the anterior portion of the lower jaw. The vessel thus formed passes along the ventral edge of the submaxillary bone, receiving in its course a number of branches from the ventral side of the head and from about the gill arches. About 4 mm posterior to the angle of the mouth this vessel unites with the naso-orbital to form the external jugular vein. From this point the external jugular vein runs posteriorly between the digastric and masseter muscles. In this part of its course the external jugular is just beneath, and closely applied to, the skin; it appears here as a sinus, the Jugular Sinus, J. S., Pl. 11, and receives numerous branches from the lateral and dorsal portions of the head; the largest of these branches is formed by the union of small branches from the temporal and masseter muscles. Just where the gills join the branchial cartilages this sinus runs ventrally for a short distance, then posteriorly and empties into the Duct of Cuvier external to the place where the subclavian vein enters. Just before making this last turn it is joined by the internal jugular.

The Lingual Vein, Li., Pl. 11, is formed not only by branches from the tongue, but also from the digastric, the ceratohyoid and the geniohyoid muscles. From its origin it runs posteriorly along the gill arches until it reaches a point lateral to the Duct of Cuvier; it then turns towards the median line and joins the subclavian vein just before it empties into the Duct of Cuvier.

The Lateral Vein, L., Pl., 11, arise near the median region of the body wall and run anteriorly along the lateral line. Just external to the Duct of Cuvier it turns from its position beneath the skin and, passing towards the median line, joins the Duct of Cuvier external to the entrance of the posterior cardinal. The lateral veins are formed from branches which join them at right angles from the septa in the abdominal muscles. These branches may form an anastomosis with the veins which pass into the liver, along the ventral mesentery, from the body wall.

VEINS OF THE ARM.

Beginning at the distal end we find that each digit has two veins, one on each side; these two veins usually unite and form single vessels, these in turn form a transverse vein on the dorsal surface of the hand which passes across the extensor digitorum communis near the proximal end of the digits. Near the middle of the hand this vein turns toward the body and runs as the RADIAL VEIN, Rdl., Pl. 11, as far as the elbow; here it is joined by a vein from the opposite side of the arm, the ULNAR VEIN, W., Pl. 11. By the junction of the radial and ulnar veins there is formed the BRACHIAL VEIN, Hum., Pl. 11; this runs along the arm between the biceps and triceps muscles, and, passing over the glenoid fossa to the lateral side, continues to a point which is anterior and ventral to the Duct of Cuvier. Here it is joined by the lingual vein and empties directly into the Duct of Cuvier. Between the glenoid fossa and the Duct of Cuvier the vein is called the SUBCLAVIAN, Sbc., Pl. 11. Just above the glenoid fossa the subclavian receives branches which come from the anterior part of the arm and from the muscles about the scapula.

PULMONARY VEINS.

The PULMONARY VEINS, P., Pl. 11, are two in number, one from each lung. They run along the latero-ventral side of the lung and unite in the mid-line anterior to the union of the two lungs. From this point of union the now single pulmonary vein runs anteriorly towards the heart, and passing to the dorsal side of the two arms of the Hepatic Sinus it usually continues in the wall of the left arm of the sinus until it finally opens into the left atrium of the heart.

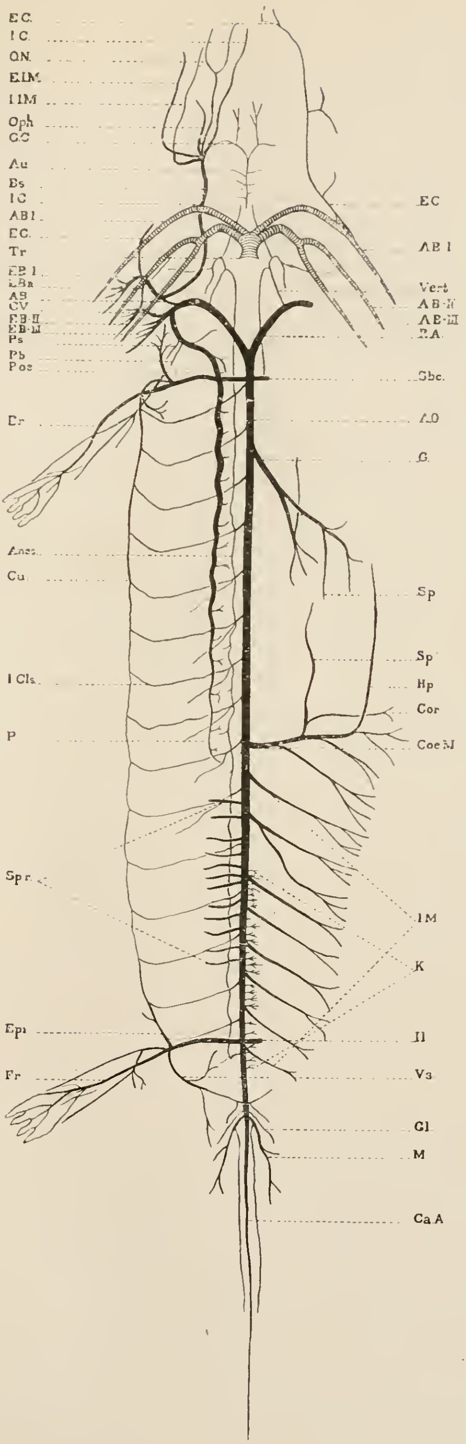
Plate 9.

Description of Plate 9.

Vascular System of *Necturus maculatus*.

The arterial system of *Necturus maculatus;* diagram somewhat less than the natural size of the animal. The dissection was made from the ventral side. The ventral aorta and its branches are represented by shaded vessels; the systemic arteries as solid vessels. The left arm and leg have been omitted from the diagram, also a few of the smaller vessels described in the text, for the sake of clearness.

A. B. Anastomosing branch between first and third efferent vessels.
A. B. I. First afferent branchial artery.
A. B. II. Second afferent branchial artery.
A. B. III. Third afferent branchial artery.
Anas. Anastomosing branch between intercostals and vertebral.
A. O. Dorsal aorta.
Au. Auditory.
Br. Brachial.
Bs. Basilar.
Ca. Caudal Aorta.
C. C. Cerebral carotid.
Coe. M. Cœliaco—mesenteric.
Cor. Coronary.
Cu. Cutaneous.
C. V. Trunk formed by the union of second and third efferent vessels.
E. B. I. First efferent branchial artery.
E. B. II. Second efferent branchial artery.
E. B. III. Third efferent branchial artery.
E. B. A. Branch to second afferent artery.
E. C. External carotid.
E. I. M. External inferior maxillary.
Epi. Epigastric.
Fr. Femoral.
G. Gastric.
Gl. Branch of caudal aorta to anal gland.
Hp. Hepatic.
I. C. Internal carotid.
I. Cls. Intercostals.
I. I. M. Internal inferior maxillary.
Il. Iliac.
I. M. Inferior mesenteries.
K. Renal.
M. Muscular branch of caudal aorta
O. N. Orbito-nasal.
Oph. Ophthalmic.
P. Pulmonary.
P. b. Muscular branch of pulmonary.
P. O. E. Oesophageal branch of pulmonary.
P. S. Muscular branch from pulmonary.
R. A. Aortic root.
Sbc. Subclavian.
Sp. Splenic branch of gastric.
Sp′. Splenic.
Sp. r. Spermatics.
Tr. Truncus arteriosus.
Vert. Vertebral.
Vs. Vesical.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AB II
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Plate 10.

Description of Plate 10.

Vascular System of *Necturus maculatus.*

Fig. 1. Afferent and efferent vessels on a larger scale than in Plate 9. The capillary connection between the two is omitted.

A. B. Anastomosing branch between first and third efferent vessels.
A. B. I. First afferent branchial artery.
A. B. II. Second afferent branchial artery.
A. B. III. Third afferent branchial artery.
A. O. Dorsal aorta.
C. V. Union of second and third efferent vessels.
E. B. I. First efferent branchial artery.
E. B. II. Second efferent branchial artery
E. B. III. Third efferent branchial artery.
E. B. a. Branch to second afferent artery.
E. C. External carotid.
I. C. Internal carotid.
P. Pulmonary.
R. A. Aortic root.
T. R. Truncus arteriosus.

Fig. 2. Arteries of the arm and hand.

Br. Brachial.
Br. a. Branch to flexor carpi radials and first digit.
Br. b. Branch to flexor carpi ulnaris and last digit.
C. a. Branch of cutaneous to upper part of arm.
Cu. Cutaneous.
Cu. a. Branch of cutaneous to pectoral muscles.
T. A. Thyroid axis.
T. a. Muscular branch of Thyroid axis.
T. a. a. Branch of T. a. to anconeus.
T. a. b. Branch of T. a. to last digit.
T. a. c. Branch of T. a. to first digit.
T. b. Muscular branch to procoro humeralis, cucularis and antibrachialis.

Fig. 3. Arteries of the leg and foot.

C. A. Branch to flexor tarsi tibialis and first digit.
C. B. Branch to flexor tarsi fibularis and last digit.
Epi. Epigastric.
Epi. B. Branch of epigastric to body wall.
Epi. R. Branch of epigastric to rectus femoris.
Fr. Femoral.
Fr. a. Muscular branch of femoral.
Fr. b. Branch to last digit.
Fr. c. Branch to flexor digitorum communis and first digit.
Il. Iliac.
Vs. an. Branch to cloaca.
Vs. c. Vesical.
Vs. gl. Branch to cloaca.
Vs. I. Muscular branch.

fig. 1

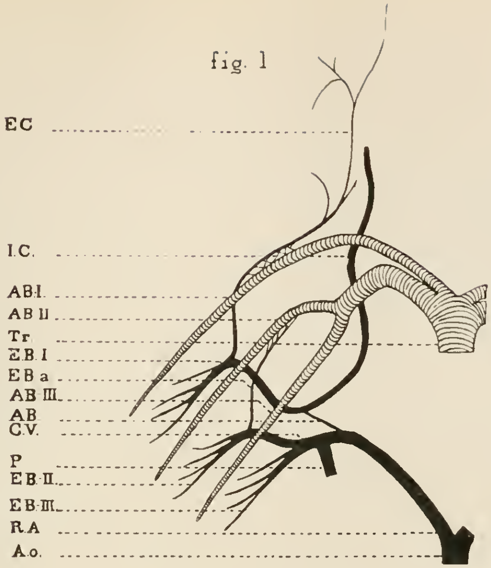


fig. 2

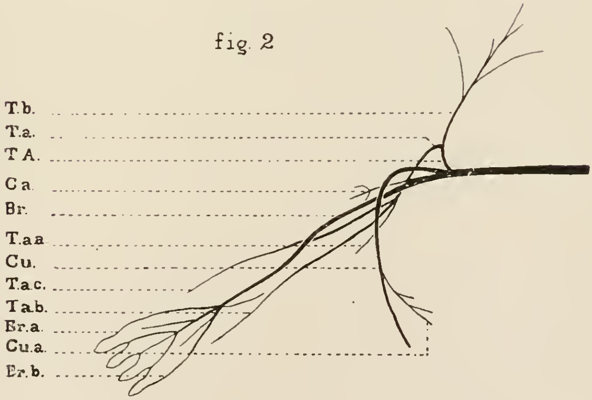


fig. 3.

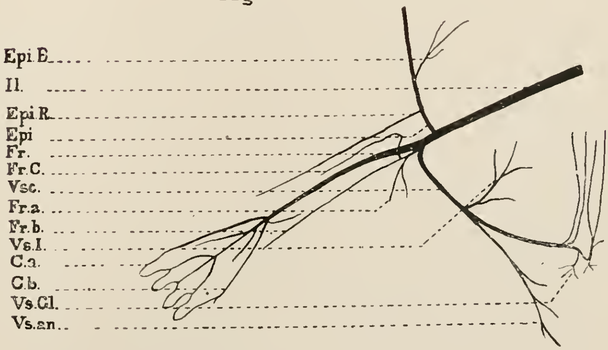


Plate 11.

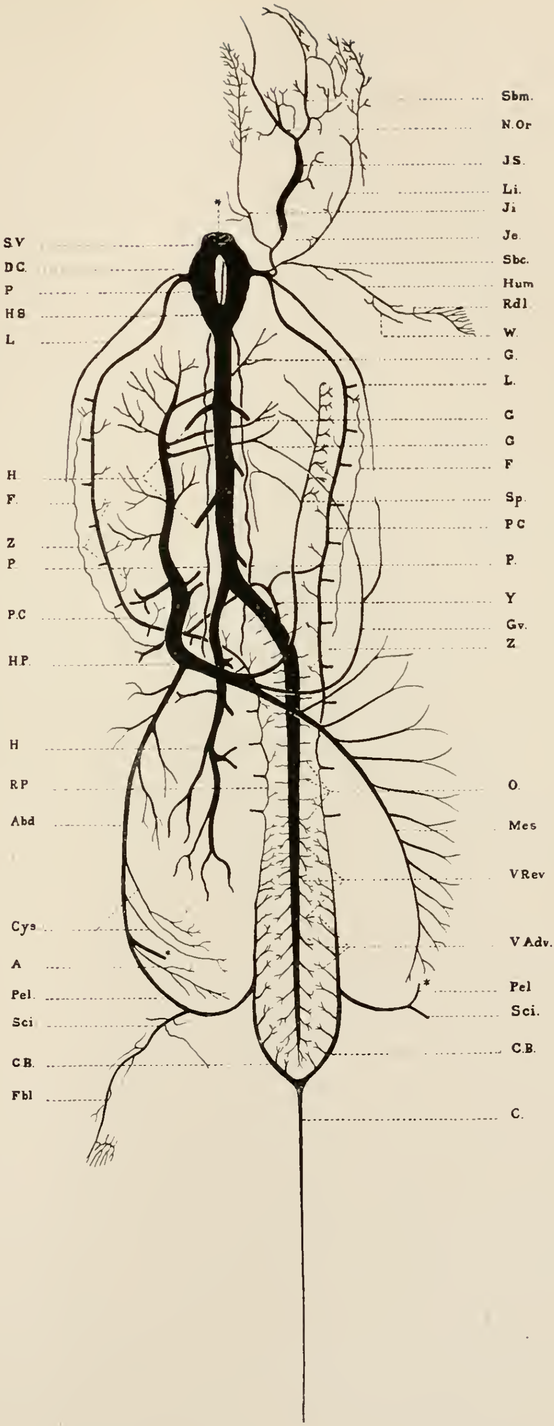
Description of Plate 11.

Vascular System of *Necturus maculatus*.....

The venous system of *Necturus maculatus*. The diagram is made from a ventral dissection. The liver has been turned over as far to the right as possible. The left arm and hand and the right leg and foot are shown. A few of the small veins and one of the large hepatic veins have been omitted for the sake of clearness.

A. Anal.
Abd. Abdominal.
C. Caudal.
C. B. Branch of caudal forming Renal Portal.
Cys. Cystic.
D. C. Duct of Cuvier.
F. Fallopian.
Fbl. Tibial.
G. Branches from stomach to hepatic.
Gv. Gastric.
H. Hepatic.
H. P. Hepatic Portal.
H. S. Hepatic Sinus.
Hum. Humeral.
Je. External jugular.
Ji. Internal jugular.
Js. Jugular Sinus.
L. Lateral.
Li. Lingual.
Mes. Mesenteric.
N. Or. Naso-orbital.
O. Ovarian.
P. Pulmonary.
P. C. Posterior cardinal.
Pel. Pelvic.
Rdl. Radial.
R. P. Renal Portal; letters placed just above anastomosis with posterior cardinal.
Sbc. Subclavian.
Sbm. Submaxillary.
Sci. Femoral.
Sp. Splenic.
S. V. Sinus Venosus.
V. Adv. Venae advehentes.
V. Rev. Venae reheventes.
W. Ulnar.
Y. Anastomosing branch between posterior cardinal and posteaval.
Z. Branches from fallopian tube to posterior cardinal.

* The single star in the upper part of the diagram indicates the position of the pulmonary vein in the *Sinus Venosus*. The two stars in the lower part of the diagram indicate the cut pelvic vein, made necessary by the reflection to the right of the liver.


Sbm.
N.Or
JS.
Li.
Ji
Je.
Sbc.
Hum
Rdl
W.
G.
L.
G
G
F
Sp.
PC
P.
Y
Gv.
Z.
O.
Mes
VRev
V Adv.
Pel
Sci.
C.B.
C.
S.V
DC.
P
HS
L
H
F.
Z
P
P.C
H.P.
H
RP
Abd
Cys
A
Pel.
Sci
CB.
Fbl

THE BRAIN OF *Necturus maculatus*.

The brain of *Necturus* is long in proportion to its width and depth. Its greatest length, measuring from the superficial origin of the olfactory nerves to the beginning of the spinal cord is about 230 mm; its greatest breadth, measuring across the caudal part of the prosencephalon is about 50 mm; its greatest depth taken through the thalamencephalon at the origin of the pituitary body is about 22 mm.

Viewed from the dorsal side, Pl. 12, and enumerating from anterior to posterior we see that the brain is composed of the olfactory lobes which pass without any sharp line of demarcation into the hemispheres of the prosencephalon; back of the prosencephalon, as an undivided body, lie the thalamencephalon and mesencephalon and pineal gland; then, as a caudal continuation of the mesencephalon, we see the epencephalon which forms a rudimentary roof of the fourth ventricle; and finally sharply separated from the mesencephalon we can see the metencephalon or medulla oblongata.

In a ventral view, Pl. 13, we see the following parts: Lying farthest anteriorly are the olfactory lobes and cerebral hemispheres, then the thalamencephalon with its broad pituitary body which covers the mesencephalon except on the lateral sides, and finally we have the metencephalon.

In a lateral view we notice that the brain vesicles lie in front of one another and that there is but an insignificant departure from the straight and unflexed condition of the embryonic brain. This is true of most of the aquatic *Urodeles* as Fish has noted.

GROSS ANATOMY.

Prosencephalon. The prosencephalon is composed of two rounded cylindrical bodies which are sharply separated by a longitudinal fissure as far as the anterior closing plate. The cylindrical bodies are about 8.8 mm long and about 2.5 mm in diameter; they are slightly concave along their lateral border and straight along their median side, and at their posterior end they are more diverging than in front. Measured dorso-ventrally they are thickest at their posterior end and gradually narrow towards the origin of the olfactory nerve. In cross section their median surfaces are shown to be flattened while their outer are convex; the union of the two surfaces is marked by a sharp angle. As there is no sharp line of demarcation between the olfactory lobes and the hemispheres, for convenience of description they will be considered together; and thus each hemisphere is to be considered as composed of the olfactory lobe and the hemisphere proper.

On the other hand, in *Rana* and in the *Chelonia* the olfactory lobes can be readily distinguished from the cerebral hemispheres. In all these cases, however, the surface of the prosencephalon is perfectly smooth and is without convolutions.

Concerning the question as to whether the olfactory portion deserves setting apart as a separate segment there is at present a variance of opinion.

Steiner, working from a physiological standpoint, argues from experiments carried on in the shark, that the prosencephalon of every vertebrate has developed phylogenetically out of the olfactory organs.

Thalamencephalon and Mesencephalon. These two are united into a short cylindrical body with no sharp line of demarcation between them. This body is flattened or even slightly concave on the dorsal and ventral surfaces. These surfaces, with the exception of the median groove on the dorsal side, are all unbroken, there being no elevations or other external indications to mark the position of the optic lobes in the mesencephalon. In this respect the brain of the *Necturus* differs greatly

from that of the *Dipnoans* on the one hand and from that of the *Rana* on the other. In both the latter cases we have the optic lobes well developed.

Anteriorly, it is sharply separated from the prosencephalon by a deep groove on the dorsal surface and a shallow one on the ventral; posteriorly, it is continued dorsally by the epencephalon or the cerebellum and ventrally by the metencephalon or the medulla oblongata. Measuring from the base of the pineal gland to the cerebellum it is about 5.8 mm long, and measured laterally it is about 3.1 mm in diameter. In cross section it will be noticed that the walls are very thick laterally, while dorsally they grow thinner until in the median line of the thalamencephalon there is only a thin layer of cells present. A cavity, the third ventricle and the Aqueduct of Sylvius, extends through the thalamencephalon and the mesencephalon and is of the same size throughout, except where the infundibulum joins it and anteriorly where it connects with the lateral ventricles of the cerebral hemispheres. At the place where the cavity of the infundibulum joins the thalamencephalon there is a V-shaped depression in the floor. At the anterior part of the cavity there is a gradual widening toward the foramen of Monroe. The relation of the pineal gland, pituitary body, optic and occulomotor nerves to these segments of the brain will be considered later.

Epencephalon. This is a short ledge which forms part of the roof of the fourth ventricle. It is thickest in its anterior part and thins out at the edges. Its general form is convexo-concave, when viewed from the dorsal side.

In the dorsal view of the brain, Pl. 12, it will be seen that the roof of the fourth ventricle extends further posteriorly than is indicated by Osborn. While he gives the roof as extending only as far as the superficial origin of the trigeminal, I found it extending further caudal, as far as the superficial origin of the facial.

Metencephalon. I consider the metencephalon as a direct posterior continuation of the ventral part of the mesencephalon,

for in forms below the mammals we have no pons to mark a dividing line.

This is the longest part of the brain, being one and one-half times as long as the rest of the brain. The metencephalon extends from the mesencephalon in front to the first pair of spinal nerves and is of the triangular shape common in the lower vertebrates. From its rounded base at the mesencephalon it gradually narrows toward the spinal cord. On the dorsal surface, Pl. 12, we see a deep triangular fossa, the fourth ventricle, which is two-thirds the length of the metencephalon, its base being at the anterior part of the medulla and its apex being drawn out into a narrow fissure posteriorly. This cavity connects with the Aqueduct of Sylvius anteriorly. Besides the fossa on the dorsal surface there is a deep median groove which corresponds to the posterior septum, and on the ventral surface, one which corresponds to the anterior fissure of the cord.

The Pineal Gland. This is well developed in *Necturus* and extends forwards between the cerebral hemispheres to near their center, Pl. 12. It is a triangular-shaped body as seen in cross section, the apex being directed ventrad. Shortly after leaving the thalamencephalon it extends dorsally, becomes narrower, and its anterior end is applied against the roof of the brain case. Serial sections show, however, that it does not penetrate it.

Osborn, judging from his paper on the Amphibian brain, thinks that the pineal gland does penetrate the cranial roof. I have not found this to be the case in the specimens I have studied; it simply flattens against the roof. The gland is solid, containing no cavity.

The Pituitary Body. This arises from the postero-ventral part of the thalamencephalon and extends backwards 5 mm to near the origin of the VIIIth nerve, Pl. 13. After proceeding a short distance it narrows, but soon widens again, thus forming a slight enlargement at the posterior end, the hypophysis. The pituitary body lies on the floor of the brain case and conforms closely to its irregularities.

The pituitary body is hollow as far as the hypophysis. This cavity is oval in cross section and as it approaches the hypophysis

gradually narrows dorso-ventrally until it is finally obliterated. The dorsal wall or roof of the infundibulum is very thin at the base of the pituitary body but increases in thickness as it proceeds posteriorly.

NERVES.

I. Olfactory. These are the most prominent pair of nerves. They arise directly from the ventro-lateral margin of the corresponding hemisphere. A sharp line on the dorsal side shows the place of origin of the nerve, but on the ventral side no sharp line of demarcation is present. On cross section the nerve is oval in shape.

In pursuing my work several peculiarities were noticed in the branching of the olfactory nerves of the brains studied. In one instance the nerve, a short distance from the olfactory lobe, broke up rapidly into branches, which ran some distance before entering the nasal capsule. This brain is the one used in the model and in the drawings. In another case the right olfactory nerve divided into two branches almost as soon as it left the lobe; but in most cases the nerve ran some distance before breaking up into its smaller branches.

II. Optic. This nerve is very small and fragile. It arises in the ventro-median line of the thalamencephalon just a little anterior to the posterior ends of the cerebral hemisphere. There are apparently no elevations or tracts at the place of origin of the optic nerve, but it seems to rise in conjunction with its fellow from the surface of the brain. The nerve runs obliquely from its place of origin, thus forming an acute angle with its fellow.

III. Oculo-motor. This nerve arises in the lateral median line at the extreme anterior part of the mesencephalon. It is very fragile and is nothing but a thread. It is very easily broken, often separating from the brain in dissecting away the meninges of the brain. It runs along the lateral surface of the brain until a short distance past the posterior ends of the cerebral hemisphere when it turns off obliquely to the muscles of

the eye. It branches before reaching the ophthalmic branch of the 5th; the branches passing on either side of this nerve.

IV and VI. Pathetic and Abducent. I consider these two nerves together because there is a great variance of opinion as to their presence or absence in the various *Amphibia*.

Osborn in his discussions of the *Amphibian* brain claims to have found both of these nerves in the *Necturus*, though he fails to show the VIth in any of his drawings and to make any definite statement about either. In his drawings he gives the VIth nerve as arising from the roof of the 4th ventricle, at a point which corresponds to the cerebellum.

Fish failed to demonstrate the IVth in *Desmognathus*. Kingsley failed to find it in the larva *Amphiuma*, but Mrs. Gage found it in a very rudimentary condition in the adult *Diemyctylus*.

As to the VIth nerve Kingsley says it is not found in the larva *Amphiuma;* Osborn, as stated at the beginning of this topic, omits it from his figures; while Reissner and Ecker describe it in the Frog, and Fisher finds it in *Siredon* and *Necturus*. With these facts in view I retraced my work, studying carefully my serial sections and the many brains which had been dissected as well as those isolated by 20 per cent. nitric acid, and I have come to the conclusion that the IVth nerve is not present in *Necturus*, and if the VIth is, it has no separate origin. My reasons for this statement are the following:

1. In serial sections I was unable to find anything that corresponded to the IVth nerve at the place where Osborn gives its origin, i. e., in front of the cerebellum. Nor could I find anything which would correspond to the origin of the VIth.

2. Finding that by studying the brain alone I was unable to find the origin of these nerves in question, I decided to dissect out the muscles of the eye and see if from this I could trace the nerves. After a careful dissection in which as far as I could see the nerves remained intact I arrived at the following results: The muscles of the eye are supplied by the IIIrd and by branches of the Ophthalmic division of the Vth. All six muscles of the eye were supplied by these nerves as well

as other muscles adjoining. The Opthalmic nerve could be traced to the Gasserian ganglia as well as the branch in question, but I could not find, as already stated, a nerve arising from a separate origin that would correspond to the VIth, and there were no nerve fibres that could have arisen from the roof of the fourth ventricle.

V. Trigeminal. This is one of the largest of the cranial nerves. The trigeminal arises from the cephalo-lateral angle of the metencephalon. It runs forward at quite a sharp angle with the brain and just before it penetrates the brain case it joins the Gasserian ganglion from which two main branches pass out, the ophthalmic and maxillo-mandibularis.

VII. Facial. This arises in conjunction with and anterior to the VIIIth on a line parallel to the Vth and a short distance caudal. Near its origin it divides into two main branches, one of which joins the Gasserian ganglion, the other and larger continuing with the VIIIth nerve for a short distance and then separating.

VIII. Auditory. This is a thick and very short nerve, which shortly after separating from the VIIth divides into two main branches, which join the auditory vesicle. It extends out at right angles from the brain and, in its final branching, becomes like a brush.

IX. Glossopharyngeal. This arises by a single origin on a line parallel with the VIIth and a short distance posteriorly. It then proceeds caudal at a sharp angle with the brain for a short distance and unites with the Vagus.

X. Vagus. This arises from two separate origins about on a line with each other, and with the IXth at a place opposite the middle of the fourth ventricle. The posterior root is the smaller and unites with the anterior root just before the IXth joins them. The joint root thus formed runs into the ganglion of the Vagus.

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PLATE 12.

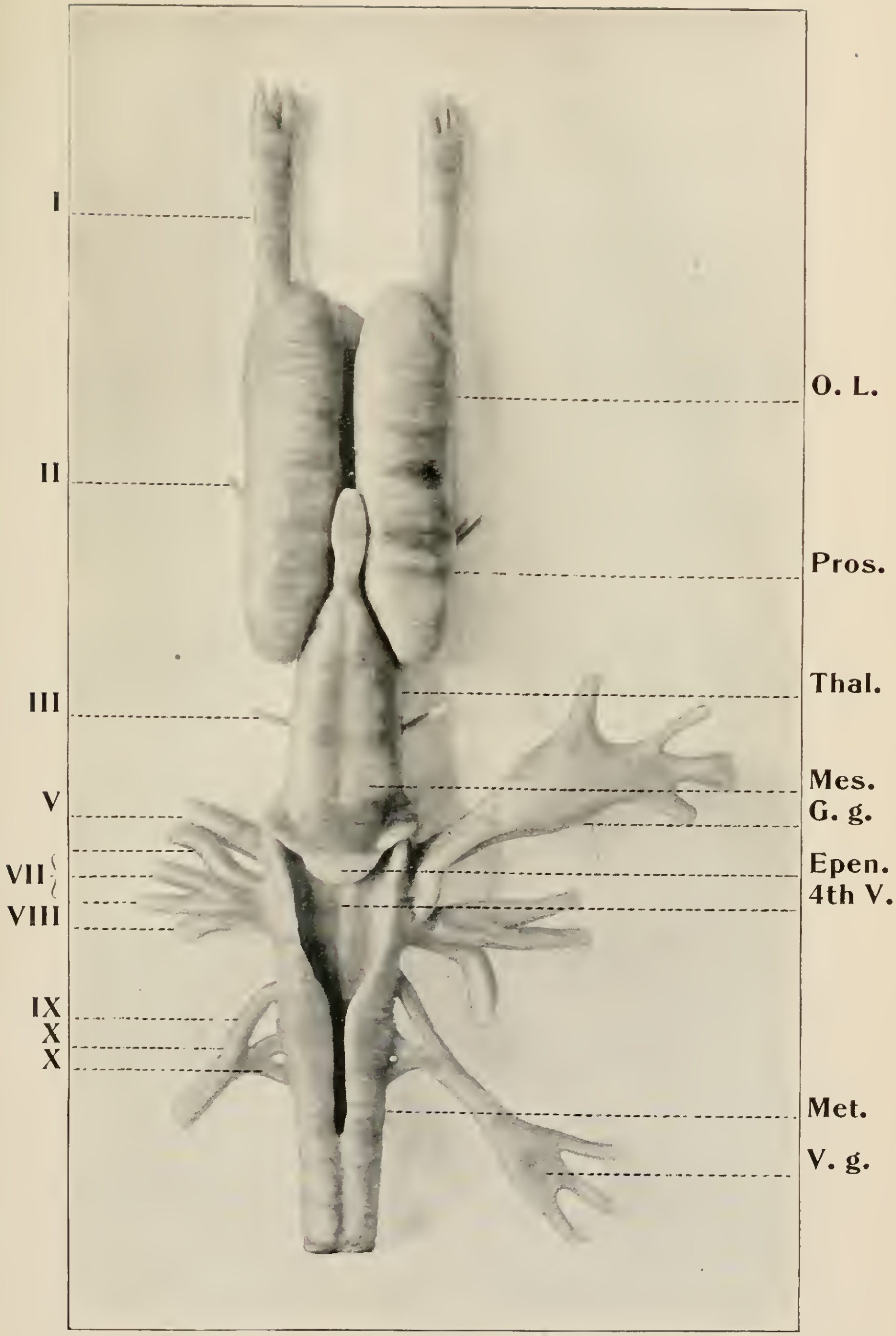
Description of Plate 12.

The Brain of *Necturus maculatus*.

Photograph of a model which was enlarged twenty diameters; in the plate it is reduced to about six and a quarter diameters. Dorsal view.

O. L. Olfactory Lobe.
Pros. Prosencephalon.
Thal. Thalamencephalon.
Mes. Mesencephalon.
Epen. Epencephalon.
Met. Metencephalon.
4th V. Fourth Ventricle.
G. g. Gasserian Ganglion.
V. g. Ganglion of the Vagus.

I. Olfactory Nerve.
II. Optic Nerve.
III. Oculo-motor Nerve.
V. Trigeminal Nerve.
VII. Facial Nerve.
VIII. Auditory Nerve.
IX. Glossopharyngeal Nerve.
X. Vagus Nerve.


I
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O. L.
Pros.
Thal.
Mes.
G. g.
Epen.
4th V.
Met.
V. g.

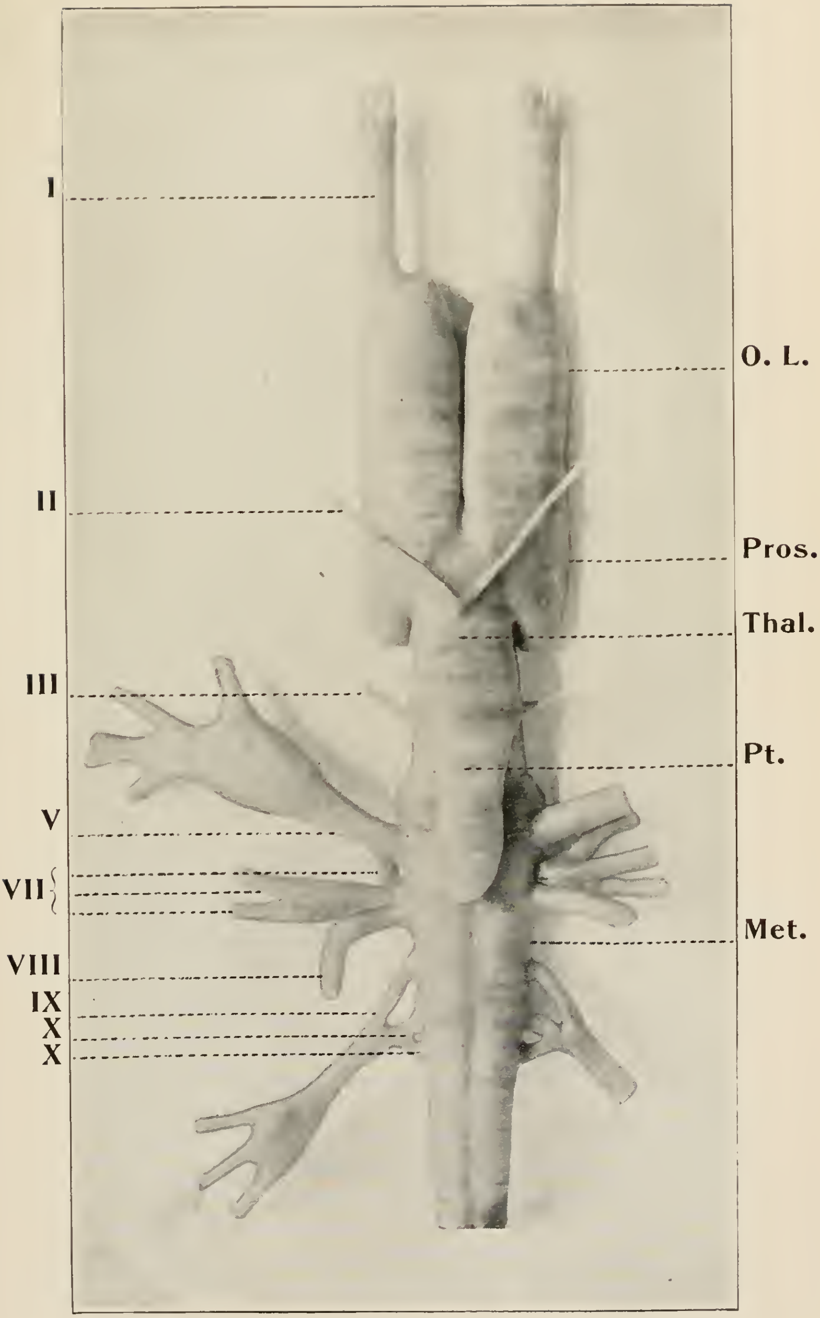
Plate 13.

Description of Plate 13.

The Brain of *Necturus maculatus.*

Photograph of a model which was enlarged twenty diameters; in the plate it is reduced to about six and a quarter diameters. Ventral view.

O. L. Olfactory Lobe.
Pros. Prosencephalon.
Thal. Thalamencephalon.
Pt. Pituitary Body.
Met. Metencephalon.
I. Olfactory Nerve.
II. Optic Nerve.
III. Oculo-motor.
V. Trigeminal Nerve.
VII. Facial Nerve.
VIII. Auditory Nerve.
IX. Glossopharyngeal Nerve.
X. Vagus Nerve.


I
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III
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VII
VIII
IX
X
X
O. L.
Pros.
Thal.
Pt.
Met.

THE EPITHELIUM OF THE PERITONEAL CAVITY OF THE CAT.

The cats used for the following study varied in age from six months up to two years. Each peritoneal cavity was examined with special reference to the epithelium of the central tendon, suspensory ligament of the liver, mesentery and great omentum. Each cat was chloroformed and bled thoroughly so as to lessen the possible chance of blood getting on the surfaces to be studied. The abdomen of the animal was then carefully opened and a piece of the omentum, of as large size as possible, was removed to the silver solution.

The remainder of the omentum was then turned aside, and a large fold of the mesentery, together with the intestine to which it was attached, was removed. The intestine was closed by means of a double ligature previous to removal, and if any blood-vessel appeared to contain a considerable amount of blood it was also ligated. The loop of intestine served as a convenient means of handling and protection from mechanical injury and was not removed until the staining was complete.

In some cases the peritoneal surfaces were stained in situ, to reduce the risk of injury to a minimum. In other cases the suspensory ligament and parts of the mesentery were removed by supporting them on a glass slide and carefully excising a portion with the scissors. The specimens were then transferred to the stain, while still on the slide, and floated off.

In all cases some one of the various solutions of nitrate of silver was used. A slight modification of Dekhuysen's method proved very satisfactory, giving sharp and clear boundary lines to the epithelial cells. In a few instances the nuclei were stained with haematoxylin.

Special effort was made to obtain as large pieces of the mesentery, omentum, etc., as possible. The great difficulty with

such large specimens was that injury was so easily done to them, thus apparently detracting from their value. Important evidence, however, was furnished in this way as will appear later.

Nearly all the specimens of the mesentery were taken from that of the small intestine, because much greater delicacy in handling the material was possible here. Some preparations were made from the meso-colon; but as these were found similar in all respects to those from the mesentery of the small intestine, and as the danger of injury was much greater owing to its situation, most of the work was done on the mesentery of the small intestine.

The Peritoneal Epithelium. All of the epithelium of the peritoneal cavity which was studied consisted of a simple layer of flat, polygonal cells, bounded by rather relaxed, wavy lines. Pl. 14, fig. 1, 2, 3. The variation in the size and form of the individual cells in the same region of the peritoneal cavity was slight, but between different regions was quite noticeable. In general it may be said that the cells of the epithelium of the mesentery were the most uniform both in size and shape. They were larger than those of the central tendon and suspensory ligament, but smaller than those of the omentum. The cells of the latter were the largest and most irregular found; they were narrower in proportion to their length and were bounded by more undulatory and distinct lines.

The cells of the central tendon, suspensory ligament and diaphragm, although smaller than those of the omentum and mesentery, resemble them otherwise quite closely. Classified in the order of their size their order would be: diaphragm, suspensory ligament, central tendon, mesentery, omentum,—the latter being the largest. If the straightness of the intercellular lines is taken as a basis the order would be: diaphragm, central tendon, mesentery, suspensory ligament, omentum,—the latter having the most wavy lines. This classification has little significance, however, for as Schwartz (20) and Muscatello (14)

NOTE.—In this paper reference to the literature is made by means of number inclosed in ( ). The titles of the papers or books referred to will be found in the Bibliography, page 245.

have shown, the shape of the cells and the condition of relaxation of their bounding lines is dependent on tension.

With the increase in age of preparation the appearance of the epithelium was found to change. Numerous granulations appeared and the nuclei were seen in clear relief. The stronger the solution of nitrate of silver used the larger and more numerous were the granules.

Owing to these phenomena it was found advisable to study all preparations immediately after they had been mounted. In preparations which had been impregnated with a weak solution of nitrate of silver (2:1000) these granules were usually absent even after being kept for some months. In some specimens numerous cast-off epithelial cells were found, but in no case was anything at all comparable to Klein's "germinating cells" found.

Stomata. Klein (7) accepts the conclusions of v. Recklinghausen (19) which he says were reiterated by Ludwig and Schweigger-Seidel (13), Dybkowsky (4), Schweigger-Seidel and Dogiel (21), and Böhm (3). Klein himself declares that "we can only consider those figures as stomata which lie in the center of radially disposed, relatively large endothelial cells." "All other indications," he continues, "are very probably only young cells formed by division of the larger." He also admits that it is a difficult question to decide whether certain structures can be called stomata or not.

Ellenberger (5) practically agrees with this view, adding that "these numerous stomata are bounded by the free ends of the imbedded nuclei." Ranvier (17), on the contrary, denies the existence of stomata and regards these structures as nothing else than "small inter-endothelial spots." Arnold (1), in his earlier writings speaks of stomata and stigmata; but in his later, he declares that "stigmata are nothing else than scattered diffusions of the fluid or semi-fluid inter-cellular substance."

Klein in a later publication than the one mentioned above (8) and especially in his joint publication with Noble Smith (9) goes much farther than any of the previous investigators, not only as to the classification of stomata, but also regarding the importance which he ascribes to them. They divide stomata

into *stomata vera* and *pseudo-stomata.* Stomata vera are small openings at the junction of several epithelial cells. They are said to be bounded by small cells in the process of division—the so-called "germinating cells." "These cells when ripe become detached and may at once be absorbed as lymph corpuscles" (*sic*).

The character of pseudo-stomata they describe as follows:

"There exist superficial branched cells in the serous membranes which lie either totally or partially between the endothelium of the surface, or, as is more commonly the case, only reach the surface by a process which projects between the superficial endothelium. * * * * We shall show * * * what great importance must be ascribed to these freely projecting cell processes; we call them pseudo-stomata."

These cell processes by budding give rise to single cells, and in certain pathological conditions cell proliferation takes place from them. Klein also makes the statement that "in female frogs, during the spawning season, the endothelial cells lining the stomata are ciliated"; a statement which I can not support and have not found corroborated by anyone.

Although the subject has received much attention from investigators there still exists a great diversity of opinion as to what are, and what are not, stomata; or, to put it differently, what are pre-formed natural openings and what are artificial. Even those authors who express a belief in the existence of stomata do not do so in an unqualified manner.

In general, stomata may be designated as small gaps or openings in the intercellular substance of serous membranes. Some investigators assert that these openings are pre—others that they are post—embryonic formations; while still others maintain that they are accidental.

One obstacle in the way of some definite conclusion is the fact that investigations have been made on different animals, or at least different parts of the same animal, under different conditions, by different methods, and with conflicting results. Another obstacle is that some investigations have been carried on to prove a preconceived idea and authors have read into every

point evidence in support of their idea without viewing the subject in an impartial manner.

The frog seems to have been especially studied, although the toad, rabbit and Guinea-pig have frequently been used. The membranes which have been most studied and where stomata have been most frequently described are the diaphragm of the rabbit and the mesentery of the frog. In a few instances the cat, mouse, dog, and in one case man, has been made the subject of investigation. The central tendon of the diaphragm has also been an object of special study, but the investigators fail to agree; the same may be said of studies of other serous membranes. Yet in spite of these facts we are told "that stomata are found with certainty in the serous membranes of all small animals" (Krause).

The methods of investigation may be classified as follows, viz., 1, absorption; 2, injection; 3, impregnation.

Absorption. This method depends upon the penetration of solutions into the superficial lymphatics and was formerly much used. Milk, blood, etc., were placed in contact with the central tendon of the diaphragm and after a little most of the fluid would be absorbed. Colored fluids, such as a solution of Berlin blue, or fluids holding fine granules in suspension, as carmine or Chinese ink, have been used. They were either introduced into the body cavity or merely brought in contact with the diaphragm by allowing them to drop on its peritoneal surface. Artificial respiration has also been used to promote absorption; it being claimed that it had a direct influence—acting as a pump (Ludwig).

Injection. This may be done either by the "puncture method" or by inserting a fine canula directly into a lymph-vessel. Dybkowsky (4) claimed that by injecting the lymphatics it could be shown that the superficial lymphatics of the intercostal pleura lead freely between the endothelium of the surface by short vertical branches. Schweigger-Seidel and Dogiel (21) conclude from an injection of the *cysterna lymphatica magna* of the frog that the body cavity was in open com-

munication with the former by means of circular openings—stomata.

Impregnation. This consists in treating the serous membranes with some stain, generally nitrate of silver, which will bring out the cell boundaries. Most of the later investigations have been carried on by this method and it is the one I have used exclusively.

Facts obtained by the first two methods, and to some extent by the last, have lead many authors to assert that the irregular distributed figures found between endothelial cells are stomata. That such figures occur can not be denied; but are they necessarily natural pre-formed openings? Or, granting that stomata are present in the frog, does it necessarily follow that they are present in mammals, which present a higher and more complex structure?

Significance of Stomata. Here again, as on the whole question of stomata, the greatest diversity of opinions exists. The greater number of the investigators who have expressed any opinion in this matter, regard stomata as free openings affording passage to the superficial lymphatics. Ludwig, Schweigger-Seidel, Klein, Rawitz, and others, speak of the passage of leucocytes through these openings, and Ellenberger (5) adds that they are sometimes plugged up with lymph cells. After referring to the work of Schweigger-Seidel and Ranvier, Ellenberger says: "These (the gaps in the intercellular substance) lead directly into the lymph-spaces."

Ranvier (17), however, did not hold this opinion, for he says:

"Most histologists consider the small inter-endothelial spots as pre-existing stomata designed for the free passage of the lymph cells; * * * but the irregular distribution of these spots and their absence if, previous to the employment of silver nitrate, the almuminate covering the surface has been removed, argues against the presence of pre-existing openings. The presence of these spots upon the omentum which is already so largely perforāted, and where the passage of white corpuscles is perfectly unnecessary, adds a further argument against the opinion of those who would call these structures stomata."

In his chapter on the structure of the capillaries Ranvier expresses himself as strongly opposed to the presence of the

stomata and stigmata described by Arnold; and, after referring to the experiments of Cohnheim, says:

"The number of stomata seem consequently to depend on the number of blood corpuscles which have passed through the walls of the vessel, and this observation suggests the thought, contrary to the conclusions of Arnold, that the stomata are not preformed but that they are produced within the capillaries by the passage of corpuscles."

Although Arnold (1) accepts the existance of stomata, he does not believe in their open communication with the lymphatic system. Rawitz (18) assumes the passage of leucocytes, but does not seem to be able to convince himself that there are free openings; he suggests that there are "at least soft places."

Tourneaux (23) believes the so-called stomata are artifacts, and says that he did not succeed in verifying a connection between the body cavity and the lymph-spaces. His conclusions were based upon experiments with starch and carmine granules, neither of which, he asserts, will penetrate into the lymph-vessels when introduced into the body cavity. He concludes by saying that the lymph cavity can be filled and the body cavity remain empty, or *vice versa,* without the passage of the starch or carmine from the one to the other.

The conclusions of Tourneaux are of special interest because they directly contradict the views given above; for most of the authors mentioned, base their opinions upon the statement that when solutions holding starch or colored granules in suspension are injected into the abdominal cavity, the granules will after some hours be found in the superficial lymph-vessels.

Muscatello (15) maintains that the central tendon of the diaphragm is the only place where stomata may be found, and even here they are somewhat doubtful. From the standpoint of absorption and diapedesis it is difficult, indeed, to see why stomata should be necessary to absorption in one region of a serous cavity and not in another. If leucocytes can pass through the walls of the blood and lymph-vessels without the presence of stomata, it does not seem a good argument to say that they are necessary elsewhere; besides if stomata are a *sine qua non* to absorption they certainly ought to be found in the intestine.

RESULTS.

The great difficulty in the preparation of all my material was the danger of mechanical injury during the removal of the specimens from the animals, during the staining, and even in mounting. As large pieces as possible were used, some measuring 20×30 mm. The difficulty in obtaining large specimens was the presence of blood-vessels and fat; these prevented the use of high powers by not allowing the cover-glass to lie close to the specimen throughout its entire extent. By the exercise of great care specimens of the above mentioned size could be obtained which showed no discontinuities, each epithelial cell being bounded by sharp, continuous lines.

The distribution of such openings or discontinuities as I was able to demonstrate in the epithelium of the peritoneal cavity of the cat was extremely irregular. Their size and shape was substantially alike on the central tendon of the diaphragm, the mesentery, omentum, suspensory ligament and the peritoneal surface of the diaphragm.

No specimens were obtained where the occurrence of these discontinuities obeyed any general rule or law. For, while specimen "A" from the suspensory ligament might have less than specimen "A" from the mesentery, specimen "B" from the former might have more than "B" from the latter. Their distribution was found to be an entirely arbitrary one with respect to the different regions of the peritoneal cavity. When present the greater majority of these figures were found at the junction of inter-cellular lines, Pl. 14, fig. 4. If, however, discontinuities were present in very large numbers, they were also found in individual lines as well as at their intersection.

All manner of variations as to size and shape were found. While in some parts of a given specimen they were more or less circular in shape and located at the junction of several intercellular lines, in other parts of the same specimen they would be arranged in chains of various sizes, but usually larger structures, which in some instances nearly equaled the adjacent cells in size, Pl. 14, fig. 6. In some specimens one or more nearly

circular openings were seen at the center of four or five radially disposed cells, Pl. 15, figs. 7, 8, 9. At first they were thought to be examples of openings plugged by lymph-corpuscles, as mentioned by Ellenberger, but a careful study of such specimens stained with nitrate of silver alone or in combination with nuclear stains showed that such was not the case. In addition to these forms still others, usually smaller than the above and more uniform in size and shape, were found. These instead of resembling small openings had the appearance of dots; they were often located at the intersection of intercellular lines or on the cells themselves, Pl. 14, fig. 5.

Closely allied to these, but less frequent in occurrence and of much greater significance, were small circular figures situated at the intersection of intercellular lines. The peculiarity of these figures was that the cell boundaries were visible either above or beneath them, and could, by careful focusing, be traced to a point of intersection.* These undoubtedly represent cases in which, owing to a slight injury, the albuminous material in the cement substance exuded in insufficient quantity to entirely obscure the underlying boundary lines; or, owing to the same cause, the silver solution penetrated beneath the epithelial cells, giving rise to a slight diffusion, Pl. 15, fig. 10.

All figures which resembled mere discontinuities or clefts were usually quite distinct and were bounded by lines very similar to the intercellular lines themselves. The more symmetrical figures were largely outnumbered by the irregular ones. This irregularity was not only one of size and shape, but also of distribution.

Stretching of a membrane at the time of its removal had the effect of producing discontinuities along the intercellular lines, Pl. 15, fig. 11. Schwartz (20) and Muscatello (14) have shown that the differences in form of endothelial cells are dependent upon the degree of contraction or distention of the organs which they line; or in other words, that the shape of the cells is de-

*The study of these figures is greatly facilitated by the use of Abbe's stereoscopic eye-piece made by Zeiss of Jena.

pendent upon the degree of expansion of the epithelial membrane.

In the case of stretched membranes the tension has been increased to a point where the cells have been torn asunder. The cement substance, albuminous in character, has exuded and given rise to dots or circular figures when exposed to the silver stain, while larger ruptures appear as various-sized and shaped openings between the cells.

Mechanical force, when applied to freshly mounted specimens in Canada balsam, would often cause separation of the cells. To show the effect of mechanical force specimens which showed, when first mounted in balsam, no openings, were subjected to various degrees of pressure. A certain relation between the distribution and number of the resultant interruptions and the force with which the cover-glasses were weighted was found to exist. The greater the weight the more numerous the openings, and if the pressure was applied to any particular part of a cover-glass a change in the shape of the cells would follow. This was manifested by a straightening of the intercellular lines and the appearance of numerous openings between the cells which radiated more or less from the center where the weight was applied.

When the epithelium was underlaid by adipose tissue, blood-vessels or Pacinian corpuscles, or in other words, when the epithelium was supported by an elastic pad, separation of the cells did not take place.

CONCLUSIONS.

As the result of my investigations I am forced to conclude that in the central tendon, suspensory ligament, omentum and mesentery of the cat there are no pre-formed natural openings commonly called stigmata and stomata.

It is true that I frequently obtained figures which corresponded with the usual description of these structures; but, owing to their great irregularity of distribution, their equally great diversity in size and shape, together with their mechanical production, I am led to regard them as accidental formations.

Indeed, my investigations have convinced me that the presence of these figures is a purely accidental and arbitrary one, due to imperfect (possibly unavoidably so) methods of preparation.

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Plate 14.

Description of Plate 14.

Peritoneal Epithelum of the Cat.

Fig. 1. Epithelium from the omentum.

Fig. 2. Epithelium from the suspensory ligament.

Fig. 3. Epithelium from the mesentery.

Fig. 4. Epithelium from the mesentery, showing that the location of the majority of the discontinuities is at the intersection of the intercellular lines. A few dots are seen which, if situated on intercellular lines, would be called stigmata.

Fig. 5. Epithelium from the suspensory ligament. Note the small figures of regular outline; some situated on the intercellular lines, others on the cells themselves. The only difference between them is their situation; if they are to be called stigmata in one situation, why not in the other?

Fig. 6. Epithelium from the mesentery. This preparation shows the widely divergent character of the intercellular discontinuities.

fig. 1.

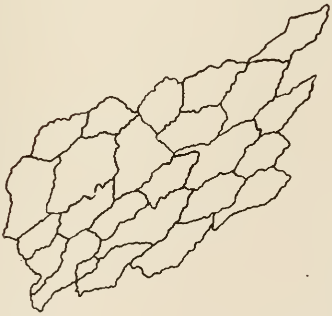

fig. 2.

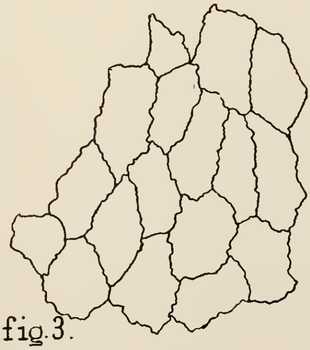

fig. 3.

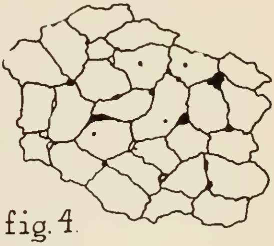

fig. 4.

fig 5.

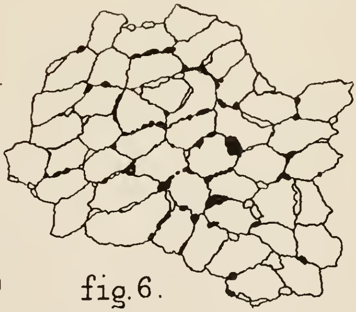

fig. 6.

Plate 15.

Description of Plate 15.

Peritoneal Epithelum of the Cat.

Figs. 7, 8, and 9. Three preparations from the mesentery. These figures are of great interest because they show how easily one might mistake the opening in the first for a stomata and in the last two figures it would be possible to say that they were small cells filling up the opening of the stomata. Their position corresponds to that assigned to stomata by Klein, i. e., "in the center of radially arranged, relatively large endothelial cells."

Fig. 10. From the mesentery. Note especially the figure which is shown more highly magnified at the left. As viewed under a low power the point indicated appears as one of the so-called stigmata, but when viewed under a higher amplification, especially if an Abbe stereoscpic eye-piece is used, it is easily seen that the dark spot is *under* the epithelial cells and that the cell boundaries are intact.

Fig. 11. From the mesentery. This figure shows the same appearance as figure 6, and also illustrates the effect of stretching.

Figs. 1–10 from the Cat; fig. 11 from the Frog. All figures were drawn under the camera lucida.

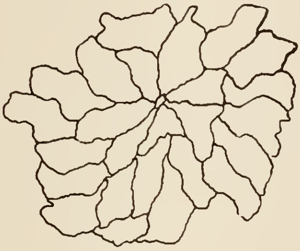

fig. 7.

fig. 8.

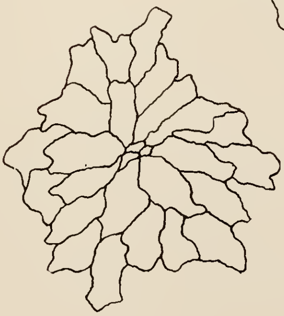

fig. 9.

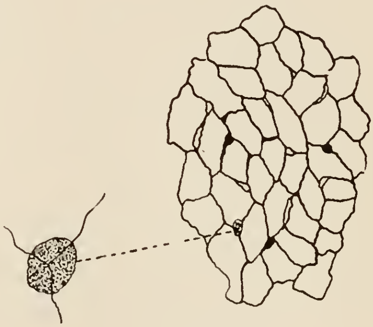

fig. 10.

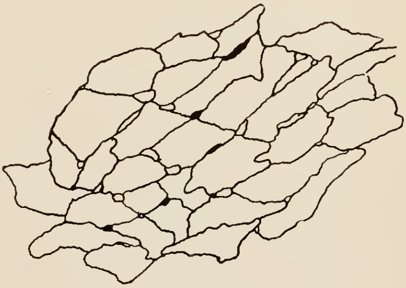

fig. 11.

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BULLETIN OF THE UNIVERSITY OF WISCONSIN

NO. 41

SCIENCE SERIES, VOL. 2, NO. 4, PP. 247-296, PLATES 16-22

THE ANOMALOUS DISPERSION OF CYANIN

BY

CARL EDWARD MAGNUSSON, PH. D.

Fellow in Physics

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PRICE 30 CENTS

Bulletin of the University of Wisconsin.

Committee of Publication

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CONTENTS.

THE ANOMALOUS DISPERSION OF CYANIN.

PART I.

HISTORICAL SURVEY.

(a) *Experimental.*—It has long been a well known fact that prisms having the same angle of refraction, but made of different kinds of glass, yield spectra which are wholly unlike one another in character. Not only is the refraction or the deviation of the light produced by one prism different from that which results when a prism of different material is employed, but the amount of dispersion, or the angular extent of the spectrum, depends likewise upon the material of which the refracting substance is composed. Moreover, to a very great extent, refraction and dispersion are independent of each other, so that media are frequently found having a high refractive index but a small dispersive power, and conversely, other media exist having small refractive power but possessing high dispersion. The angular distance between any two given wave lengths in the prismatic spectrum depends, therefore, not only upon the refracting angle of the prism but upon the nature of the material of which the prism is made, so that in general, prismatic spectra are unlike one another both in angular extent and in angular distance between corresponding wave lengths. This variability in the character of prismatic spectra is known as the irrationality of dispersion.

Until the year 1840 no exception had been found to the general law that short waves are deviated more than longer ones, that is to say, that the order of arrangement of colors in the spectrum is always the same although the distances between any

two given wave lengths may vary considerably. At about this time Fox Talbot, while working with the double oxalate of chromium and potash, made the remarkable discovery that prismatic crystals of this substance have the power of deviating the red more than the blue. Nothing was published on the subject, however, until nearly twenty years later, when Le Roux[1] announced the fact that by a hollow glass prism filled with iodine vapors the red rays are bent more than the blue. Talbot[2] at once recalled his early experiments and published an account of what he had done. Speaking of the arrangement of the colors in the spectrum produced by the double oxalate of chromium and potash, he says: "The colors were very anomalous, and after making many experiments I came to the conclusion that they could only be explained by the supposition that the spectrum, after proceeding for a certain distance, stopped short and returned upon itself."

M. Hurion[3] made quantitative measurements upon iodine vapors and found the refractive index for the violet and red rays at 700° C to be $\mu_v=1.019$; $\mu_r=1.0205$.

The first real impulse for extensive work upon this phenomenon was given by Christiansen[4] in 1870, when he discovered anomalous dispersion in an alcoholic solution of fuchsin. Christiansen noticed that in the transmitted beam the green light was absent, that the red, orange, and yellow rays were refracted in their usual order, but that the violet was deviated less than the red, so that a dark band lay between it and the red.

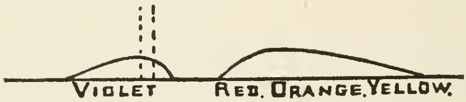

FIG. 1.

The relative arrangement of the colors in this spectrum is shown in figure 1, in which the approximate intensities of the

[1] Le Roux, Comp. Rend., LV., p. 126 (1862). Pogg. Ann. CXVII., p. 659; Ann. de Chim. et de Phys. (3) LXI., p. 285 (1861).

[2] Talbot, Proc. Roy. Soc. Edin. 1870–1871.

[3] M. Hurion, Jour. de Phys. (1), VII., p. 181.

[4] Christiansen, Pogg. Ann. CXLI., p. 479; CXLIII., p. 250; CXLVI., p. 154.

light are represented by the height of the respective ordinates. The great dispersive power of fuchsin became at once apparent on comparing lengths of the spectra produced by the dye and by pure alcohol, that due to the latter being represented by the dotted lines in the figure. For an 18 per cent. solution of fuchsin in alcohol, Christiansen obtained the following indices of refraction:

TABLE I.

Fraunhofer Lines.	B.	C.	D.	E.	F.	G.	H.
18 per cent. Fuchsin solution....	1.450	1.502	1.561	....	1.312	1.258	1.312
Pure alcohol.....................	1.3628	....	1.3654	1.3675	1.3696	1.3733	1.3761

He worked with solutions of different concentrations and showed that the refractive index increases with the density of the solution, but that this increase is different for the various wave lengths.

When Christiansen published his first results the subject was taken up very energetically by Kundt,[1] who repeated the work on fuchsin and examined many of the aniline dyes and other colored solutions, such as indigo, carmine, and potassium permanganate. Many of these substances show "surface color," that is, they have the power of reflecting certain colors more than others. Kundt made extensive experiments to show the interdependence of the two phenomena and came to the conclusion that all substances which show "surface color" also give anomalous spectra. Continuing his experiments he found that a very close relation exists between dispersion and absorption, and that anomalous dispersion depends upon the selective absorption of the medium and not upon the "surface color." This discovery of the relation between absorption and dispersion has been of the greatest importance and has enabled later investigators to contribute much to our knowledge of dispersion. Kundt embodied his conclusions in the following statement, which is known as Kundt's Law,[2] to which no exception has as

[1] Kundt, Pogg. Ann. CXLII., p. 163; CXLIII., pp. 149, 259; CXLIV., p. 128: CXLV., pp. 67, 164.

[2] Kundt, Pogg. Ann. CXLIII., p. 265.

yet been found: "Coming from the red end of the spectrum and approaching an absorption band the refractive index is abnormally increased, and coming from the violet end towards the absorption band the refractive index is abnormally decreased."

To make the peculiar variations in the refractive index directly visible to the eye, Kundt employed the method of crossed prisms[1] as first used by Newton[2] in ordinary dispersion. A beam of white light is first dispersed by a glass prism placed with its refracting edge vertical. This spectrum is then passed through a hollow prism filled with an alcoholic solution of cyanin and placed with its refracting edge horizontal. Thus the prisms have their refracting edges at right angles to each other so that the first one deviates the light in a horizontal plane while the second bends the rays in a vertical direction. Suppose the deviation is simply inversely proportional to the wave length, that is, a normal spectrum, such as is produced by a grating, in each case, the resulting crossed prism spectrum will become a diagonal band having the violet end elevated. This is seen in (a), Fig. 2. The lower band shows the appearance of the spectrum produced by the first prism only, while

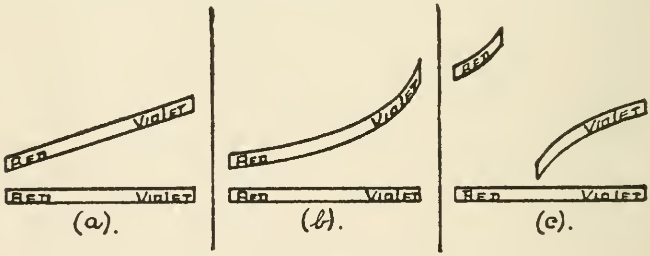

FIG. 2.

the diagonal band represents the final result after passing through both prisms. If now the dispersion of the second prism was irrational, as is the case with ordinary glass, the final result would be a curved band as is seen in the upper part of (b), Fig. 2. If the common glass prism is removed and a hollow prism filled with a cyanin solution, as used by Kundt,

[1] Kundt, Pogg. Ann. CXLIV., p. 133.
[2] Newton's Opticks, Book I, Prop. II.

is placed in the second position, the crossed prism spectrum will be broken into two bands as is seen in (c), Fig. 2. The red is deviated very much and the band turns up sharply as the orange is approached; the yellow is absorbed, and hence, absent, leaving the spectrum in two parts; the green is bent least, while the deviation rapidly increases as the violet is approached. This method is very striking to the eye and gives an easy means of determining roughly the nature of a spectrum.

With the dye in solution and placed in a common hollow prism, the deviation produced by the solvent is superimposed upon that made by the dye itself. To separate the two, Soret[1] made a glass trough with parallel sides, having a diagonal glass partition. On one side he poured the solution and on the other the pure solvent. Consequently, any deviation in the light was due to the dissolved substance only and not to the solvent. Still, it must be noted that a substance when dissolved may not have the same optional properties as when in the solid state. For the same purpose DeKlercker[2] used two hollow prisms of the same angle and placed in opposite directions, the one being filled with the solution and the other with the solvent.

Quantitative measurements, by the ordinary spectrometer method, for determining the refractive index for various wave lengths have been carried out by several physicists. Sieben[3] and Ketteler[4] in particular made a large number of observations upon various substances, in several solvents, and at different temperatures and concentrations. Among the solvents used were alcohol, chloroform, and water. Their aim was to make experimental observations upon which they could base a theory that would explain this strange phenomenon. This experimental data was afterwards used by Ketteler in his theoretical deductions and some important results were reached. Still, it cannot be said that he succeeded in establishing the theory advanced, inasmuch as it is evident that a substance in solution

1 Soret, Pogg. Ann. CXLIII., p. 325, (1871).
2 DeKlercker, Comp. Rend. LXXXIX. (1879).
3 Sieben, Wied. Ann. VIII., p. 137; XXIII., p. 312.
4 Ketteler, ibid. XII., pp. 363, 481.

may have entirely different optical properties from those which it possesses in a solid state.

To avoid this objection several indirect methods based upon the properties of the solid dye were devised. The results obtained do not warrant a detailed description, but a bare statement of the methods used will be made. Sieben employs a method based on the total reflection of light from the surface of the solid dye. By measuring the absorption of the solid dye for various wave lengths, Wernicke[1] was able to calculate the index of refraction, and for fuchsin his results are given in Table II.

TABLE II.

λ	581	571	532	483	466	488	438
μ	2.326	2.372	1.875	1.530	1.288	1.224	1.295

Wiedemann,[2] Lundquist,[3] and Merkel[4] made observations to determine the elliptic polarization of the light reflected from the surface of the solid substance. The work of these and several other observers, although of great interest, is so dependent upon a number of doubtful assumptions that to show the real value of the results a detailed description must be made. The latter is outside the limit of a brief outline and must be omitted. Although the refractive index, and therefore, also, the velocity of the light in the substance can be calculated by these indirect methods, still, the direct observation of refraction by a solid prism is by far the simplest and surest procedure. As early as 1875 Wernicke[5] determined the indices given in Table III., by means of a prism of solid fuchsin.

TABLE III.

Fraunhofer lines.	A.	B.	C.	G.	H.
μ	1.73]	1.81	1.90	1.31	1.54

1 Wernicke, Pogg. Ann. CLV., p. 87.

2 Wiedemann, ibid. CLI., p. 1, (1874).

3 Lundquist, ibid. CLII., pp. 177, 398, 565, (1874).

4 Merkel, Nov. Act. Roy. Soc. Upsala, Ser. III.

5 Wernicke, Pogg. Ann. CLV., p. 93, (1875).

It appears that only one prism was made and that was far from being satisfactory, for in speaking of the results Wernicke says that the A and B lines were "plain," the rest "uncertain." The D, E, and F lines could not be determined as the prism absorbed all the light in this part of the spectrum.

It was almost twenty years later that Pflüger[1] succeeded in making solid prisms of several of the aniline dyes. The method of making the prisms is as follows: A piece of glass tubing is laid upon a piece of plate glass, and in the prismatic opening between the two an alcoholic solution of the dye is placed, drop by drop, and allowed to evaporate. The solid dye will thus fill up the prismatic space between the tube and the plate. When the deposit is of the desired thickness, the process is stopped, the glass tube removed by a sharp blow, and a small bi-prism is thus left on the glass plate. This is simple in theory but tedious in practice. To secure three good prisms Pflüger[2] made over three hundred attempts, and still even the best had optically poor surfaces. Since the angles of the prisms used by Pflüger were very small, the largest being 2′ 9″.6, the irregularities in the surface became serious sources of error, inasmuch as a small error in measuring the angle of the prism produces a large percentage error in the results. With solid prisms of several of the aniline dyes, formed in this manner, Pflüger determined the refractive indices, for the visible part of the spectrum, by the usual direct spectrometer method.

Fuchsin and cyanin received the most attention and the average results obtained by four prisms of the latter are given in Table IV.[3]

TABLE IV.

λ	700	671	656	645	620	589	565	540	535	520	505	486
μ	2.05	2.13	2.19	2.23	1.94	1.71	1.39	1.25	1.20	1.19	1.28	1.40

With cyanin he extended his experiments into the ultra violet. To do this he used an iron arc spectrum, dispersed by a

[1] Pflüger, Wied. Ann. LVI., p. 412, (1895); LXV., pp. 173, 214, 225, (1898).
[2] Pflüger, ibid. LXV., p. 205, (1898).
[3] Pflüger, ibid., p. 206.

Rowland's concave grating. Between the grating and its focus he placed the small cyanin biprism with its refracting edge parallel to the lines of the grating. The double set of bright lines thus formed at the focus were photographed. The distance between the corresponding lines in the two sets were measured and from these measurements the refractive indices were calculated. These results are given in the following table:

TABLE V.

Prism.	α	438	407	405	378	350	288
1	83″			1.70		1.70	1.71
0	126.″4	1.59	1.68		1.69		
Mean μ		1.59	1.68	1.70	1.69	1.70	1.71

The objective point of Pflüger's work was to test the Ketteler-Helmholtz dispersion formula, the derivation and form of which will be given in the theoretical part of this paper. The equations require experimental data for both the extinction and refraction indices. To find the former, Pflüger employed a König's spectro-photometer, by which the absorption of the light, when passing through a thin film of cyanin, was measured. The ratio between the original intensity, I, and the strength after passing through the film I′, is found by equation (1), where a is given by the reading of the photometer.

$$\frac{I}{I'} = \text{Cot}^2 \alpha \qquad (1).$$

The extinction index, X, is then calculated by the usual formula, (2), where d is the thickness of the film, λ the wave length of the light in free space, and e the base of the natural system of logarithms.

$$\frac{I}{I'} = e^{-\frac{4\pi X d}{\lambda}} \qquad (2).$$

In the series of papers published by Pflüger are found several tables for the extinction index. The disagreement between the calculated and observed values led him to repeat this work with

special care and the results for solid cyanin films given in his last[1] paper are shown in Table VI.

TABLE VI.

λ	635	620	589	570	565	535	520	505	486	440	400
μ	0.53	0.67	0.69	0.75	0.74	0.46	0.26	0.15	0.06	0.00	0.00

Pflüger made an elaborate comparison of these data with the values calculated by the Ketteler-Helmholtz dispersion formula.

To overcome the difficulties of making prisms by Pflüger's method and in hopes of securing better results R. W. Wood[2] dissolved the dye in Canada balsam and poured the solution while hot into the V shaped opening between two glass plates. Although the prisms thus made were superior to those obtained by Pflüger, the dye was still in solution and the same objection could be made as for dyes in alcoholic solution. He next tried to fuse several of the aniline dyes and found that with cyanin this was a singular success. While in a fluid state the cyanin was pressed into an acute prism between two pieces of plate glass. After cooling, one of the plates was removed by a sharp blow, the prism remaining fixed on the other. The advantages of this method are several:

1st. The rapidity and comparative ease of making good prisms.

2nd. The increased accuracy of the measurement of the refracting angle which the superiority of the optical surface makes possible.

3rd. The improved definition of the transmitted beam on account of the uniformity of the prism.

4th. The ability to obtain prisms of almost any desired angle. Pflüger considers an angle of 2′ 6.″4 remarkably large while by this method prisms have been made with a refracting angle of 2° and over and no special difficulty would be met if larger angles were desired.

[1] Pflüger, Wied. Ann. LXV., p. 227.

[2] Wood, Phil. Mag. XLVI., p. 380, (1898).

(*b*) *Theoretical.*—The great importance of the phenomenon of anomalous dispersion in the theory of light is, perhaps, best seen when the various theories framed for the explanation of dispersion are examined. Kundt's discovery of the evident dependence of dispersion upon absorption rendered necessary a thorough revision of the older theories regarding this phenomenon.

The fundamental assumption of the wave theory of light is the existence of a medium, called the ether, which pervades all space and in which luminiferous vibrations are propagated as if in an elastic solid. Upon this basis the velocity of transmission of a light wave is given by the expression,

$$V = C\sqrt{\frac{E}{D}} \qquad (3).$$

where E is the elasticity of the medium; D, its density; V, wave velocity; and C, a constant.

To account for the difference in the velocity of the transmission of light in transparent media and in free space by this equation, three suppositions may be made.

(a). E may be constant and D variable, $\therefore V = \frac{C_1}{\sqrt{D}}$ (4).

(b). E may be variable and D constant, $\therefore V = C_2 \sqrt{E}$ (5).

(c). Both E and D may vary, $\therefore V = C\sqrt{\frac{E}{D}}$ (6).

The first assumption was made by Fresnel[1] while the theories of Neumann[2] and McCullagh[3] depend upon the second. Both assumptions lead to identical results, except, that the plane of vibration must be considered perpendicular to the plane of incidence in the first case and parallel to it in the second. The third case, if treated by methods similar to those employed by Fresnel, Neumann, or McCullagh, leads to results not agreeing with known facts. These theories would be sufficient to explain

[1] Fresnel, Ann. de Chim. et de Phys. XLVI., p. 225. Oeuvres compléte, I., p. 767.

[2] Neumann, "Vorlesungen über Theoretische Optik," edited by Dr. E. Dorn, Leipzig, 1885.

[3] McCullagh, Trans. Roy. Soc. Irish Acad. Vol. XXI.

refraction if all colors were deviated the same amount, but for dispersion, or the difference in the velocity of transmission of light of various wave lengths they offer no solution.

To explain the fact that in material media light waves, differing in wave length, are propagated with different velocities, while in free space all light waves are transmitted with the same velocity, Cauchy[1] made the following assumptions:

1st. That the ether is of a granular structure.
2nd. That there is a certain attractive force between ether and matter so that inside a material body the ether is very much denser than in free space.
3rd. That the distance between the ether particles inside the body is comparable to the wave length of light, while in free space it is of a different order.
4th. That the period of vibration of a wave is constant, and hence, that the wave length varies with the velocity of transmission.

From these assumptions Cauchy developed the following expression for the velocity of transmission of light in terms of the wave length in the medium:

$$V^2 = A_1 + A_2 \left(\frac{2\pi}{\lambda}\right)^2 + A_3 \left(\frac{2\pi}{\lambda}\right)^4 + \&\text{ct.} \qquad (7).$$

where A_1, A_2, A_3, etc., are constants depending upon the nature of the medium. While calculating the values of these constants he observed that this series is rapidly converging and that for all practical purposes it may be sufficient to use the first two terms, thus:

$$V^2 = A_1 + A_2 \left(\frac{2\pi}{\lambda}\right)^2 \qquad (8).$$

From his 4th assumption there results: $\lambda : \lambda' :: \nu : \nu'$ where λ is the wave length in free space and ν the velocity. Combining this with equation (8), making a series of transformations, and

[1] Cauchy, Memoire sur la dispersion de la lumière. Prag. 1836. Beer:—Einleitung in der höheren Optik, p. 209, Braunschweig, 1853.

dropping terms of higher order, he derived the following equation for the index of refraction:

$$\frac{1}{\mu^2} = A_1 + \frac{A_2}{\lambda^2} + \frac{A_3}{\lambda^4} + \text{\&ct.} \tag{9}$$

Christoffel[1] showed that when Cauchy made his transformations to derive (9) from (8) he assumed A_2 to be small in comparison with A_1 and, hence, practically used only one constant. Christoffel devised a new method of solving equation (8) that did not require the second assumption, and showed that the index of refraction can be represented by equation (10):

$$\mu = \frac{n_0 \sqrt{2}}{\sqrt{1 + \frac{\lambda_0}{\lambda}} + \sqrt{1 - \frac{\lambda_0}{\lambda}}} \tag{10}$$

The problem of dispersion was also studied by Redtenbecker[2] and upon the supposition that each molecule is surrounded by a dense ether shell he obtained the formula:

$$\frac{1}{\mu^2} = A + \frac{B}{\lambda^2} + C\lambda^2 \tag{11}$$

The subject was next treated by Briot.[3] He considered the assumptions made by Cauchy insufficient to explain dispersion, inasmuch as a change in density alone could not give a different *order* to the distances between the ether particles, and consequently, if the wave length were a function of the velocity inside a material body the same must be true in free space. To remedy this defect he assumed a direct action of the material particles upon the velocity of the transmission of light and expressed this by adding a term $K\lambda^2$ to Cauchy's formula, thus:

$$\frac{1}{\mu^2} = K\lambda^2 + A_1 + \frac{A_2}{\lambda^2} + \frac{A_3}{\lambda^4} + \text{\&ct.} \tag{12}$$

This formula he tested by the best experimental data obtainable and found that the term $K\lambda^2$ was small and in most cases could

[1] Christoffel, Pogg. Ann. CXVII., p. 27, (1861).
[2] Redtenbecker, Dynamiden-System. Mannheim, (1857).
[3] Briot, "Essai sur la théorie mathématique de la lumière." Paris, 1863; Leipzig, 1867; C. R. LVII., p. 866.

be neglected. Ketteler[1] in 1870 determined the value of the constants, in Briot's formula, for several substances and found that the calculated values for the index of refraction agreed closely with those observed.

It was at this time that Christiansen and Kundt brought the phenomenon of anomalous dispersion into prominence. These remarkable observations could not be explained by either Cauchy's or Briot's equations, but rendered necessary the construction of a new theory.

Sellmeier[2] made the first attempt and laid the basis for further work. His assumptions are as follows:

1st. The existence of an ether of constant elasticity and density.

2nd. The retardation of the light is entirely due to the interaction between the ether and the material particles.

3rd. The intensity of the interaction depends upon the ratio between the natural period of vibration of the material particles and of the wave length, and that an absorption line results when this ratio is unity.

4th. That each material particle is entirely free to vibrate without affecting the other particles.

Several minor assumptions are made in the development of the first equation to simplify the calculations or even to make them possible.

From these assumptions Sellmeier deduces the following formula for the refractive index:

$$\mu^2 - 1 = \Sigma \frac{\dfrac{m\ t^2\ a_0^2}{t^2 - d^2}}{m'\ a^2} \qquad (13).$$

Where t equals period of vibration of λ.

Where d equals natural period of vibration of material particle.

Where a_0 equals amplitude of center of gravity of material particle.

Where a equals amplitude of ether vibration.

Where m′ equals mass of ether in unit volume.

Where m equals mass of matter in unit volume.

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[1] Ketteler, Pogg. Ann. CXL., p. 1.

[2] Sellmeier, Pogg. Ann. CXLV., pp. 399, 520; CXLVII., pp. 387, 535, (1873).

It is noteworthy that Lord Kelvin[1] in a paper read before the Royal Society of Edinburgh, February 6th, 1899, on the absorption line of sodium vapors, used Sellmeier's formula.

Kelvin's[2] theory is quite similar to that of Sellmeier, the chief peculiarity being the conception of concentric spherical shells, connected by zigzag springs, to represent a molecule having more than one natural period of vibration.

Under the assumption of a diatomic molecule of this form he writes the equation thus:

$$\left(\frac{V_2}{V_1}\right)^2 = 1 + \frac{m\ T^2}{T^2 - K^2} + \frac{m_1\ T^2}{T^2 - K_1^2} \qquad (14).$$

Where T equals period of vibration of ether light wave.
Where K equals natural period of vibration of one shell.
Where K_1 equals natural period of vibration of the other shell.
Where m equals density of 1st shell, using ether as unity.
Where m_1 equals density of 2nd shell, using ether as unity.

This theory of mutual reaction between matter and ether was next developed by Helmholtz.[3] Let u, v, w, be the displacements of the ether particles of density m, in an element of volume dv; U, V, W, the displacements of the material particles of density m′; then, considering the forces along X axis only, he forms two equations of motion, thus:

$$m\,\frac{d^2 u}{dt^2} = X + X' + A + \&ct. \qquad (15a).$$

$$m\,\frac{d^2 U}{dt^2} = X_1 + X'_1 + A_1 + \&ct. \qquad (15b).$$

Where X equals action of ether particles external to dv;
Where X′ equals external impressed force on m.
Where A equals direct action of the material particle in dv on the ether;
Where X_1 equals action of matter external to element dv.
Where X'_1 equals external impressed force on m.
Where A_1 equals direct action of the ether in dv on the material particles.

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[1] Kelvin, Phil. Mag. XLVII., p. 302.
[2] Kelvin, Baltimore Lectures, 1884.
[3] Helmholtz, Pogg. Ann. CLIV., p. 582.

To derive expressions for these forces, Helmholtz made the following assumptions:

1st. The impressed forces are supposed to vanish; hence:

$$X_1 = X_1' = 0.$$

2nd. The medium is supposed to be perfectly elastic; hence:

$$X = a^2 \frac{d^2u}{dz^2} \tag{17a}$$

$$X_1 = -a^2 U - \gamma^2 \frac{dU}{dt} \tag{17b}$$

3rd. The force of restitution in an elastic medium is proportional to the displacement; hence:

$$A = \beta^2 (U - u) \tag{18}$$

4th. The action is supposed to be confined to the element of volume dv; hence:

$$A + A_1 = 0 \tag{19}$$

Substituting the values thus found for X, X_1, X', X'_1, A and A_1 in (15a) and (15b) we have:

$$m \frac{d^2u}{dt^2} = a^2 \frac{d^2u}{dz^2} + \beta^2 (U - u) \tag{20b}$$

$$m' \frac{d^2U}{dt^2} = -\beta^2 (U - u) - a^2 U - \gamma^2 \frac{dU}{dt} \tag{20b}$$

These are the fundamental differential equations in Helmholtz's dispersion theory. Solving, he finds:

$$\mu^2_0 - X^2 - 1 = \frac{B\lambda^2}{m h^2_m} + \frac{\frac{B}{m m'} \frac{\lambda^4}{\lambda^4_m} \left[\left(1 - \frac{B}{m'}\right)\frac{\lambda^2}{\lambda^2_m} - 1\right]}{\left[\left(1 - \frac{B}{m'}\right)\frac{\lambda^2}{\lambda^2_m} - 1\right]^2 + G^2 \frac{\lambda^2}{\lambda^2_m}} \tag{21a}$$

$$2 \mu_0 X_0 = \frac{\frac{B^2}{m m'} G \frac{\lambda^5}{\lambda^5_m}}{\left[\left(1 - \frac{B}{m'}\right)\frac{\lambda^2}{\lambda^2_m} - 1\right]^2 + G^2 \frac{\lambda^2}{\lambda^2_m}} \tag{21b}$$

Where μ_0 equals the refractive index at perpendicular incidence; x_0, the extinction coefficient, for λ at perpendicular incidence; and λ_m, wave length of absorption band.

Lommel[1] makes the same arguments as Helmholtz except for the force A, but considers the "action to follow Newton's law of friction," and, hence, his fundamental equations become:

$$m \frac{d^2u}{dt^2} = a^2 \frac{d^2u}{dz^2} \mp \beta^2 \frac{d}{dt}(U - u) \tag{22a}$$

$$m' \frac{d^2U}{dt^2} = \pm \beta^2 \frac{d}{dt}(U - u) - a^2 U - \gamma^2 \frac{dU}{dt} \tag{22b}$$

Lommel gave the first set of signs but Ketteler[2] and Voigt[3] argued that the lower set should be used. Lommel[4] replied, still defending his first position, but, in the opinion of Glazebrook,[5] without success.

Solving equations (22) and (23)

$$\mu^2_0 - X^2_0 - 1 = \frac{\frac{B'^2}{m\,m'} \frac{\lambda^2}{\lambda^2_m}\left(\frac{\lambda^2}{\lambda^2_m} - 1\right)}{\left(\frac{\lambda^2}{\lambda^2_m} - 1\right)^2 + \left(\frac{B'}{m'} - G\right)^2 \frac{\lambda^2}{\lambda^2_m}} \tag{23a}$$

$$2\,\mu_0\,X_0 = \frac{B'\,\lambda^2}{m\lambda^2_m} + \frac{\frac{B'^2}{m\,m'}\left(\frac{B^2}{m'} - G\right)\frac{\lambda^3}{\lambda^3_m}}{\left(\frac{\lambda^2}{\lambda^2_m} - 1\right)^2 + \left(\frac{B'}{m'} - G\right)^2 \frac{\lambda^2}{\lambda^2_m}} \tag{23b}$$

Ketteler[6] makes a third suggestion. He supposes the action between ether and matter to be proportional to the acceleration instead of the velocity as suggested by Lommel, therefore, expressing the force A thus:

$$A = \frac{\delta^2}{\delta t^2}(U - u) \tag{24}$$

The resulting equations when solved can be reduced to those of Helmholtz by making $B\lambda^2 = B''$. Ketteler[7] has written a large

[1] Lommel, Wied. Ann. III., p. 339.

[2] Ketteler, ibid. XVIII., p. 387.

[3] Voigt, ibid. XVII., p. 468.

[4] Lommel, ibid. XIX., p. 908.

[5] Glazebrook, B. A. A. S. Report, 1885, p. 222.

[6] Ketteler, Theoretische Optik, p. 78.

[7] Ketteler, Wied. Ann. XVI., p. 86; XII., p. 363; XV., p. 613; XVIII., pp, 387, 631; XXI., pp. 199, 178; XLIX., pp. 382, 509; LIII., p. 823.

number of papers, in which dispersion is discussed from several points of view. To briefly state his views would be impossible, still, the main idea in his works on dispersion seems to be this: the mutual reactions between ether and matter, that is, the A′ and A forces, are unknown, and, hence, they should be eliminated from equations. The total work done per unit of time on the whole system is equated to the rate of change of kinetic energy, and in this the mutual reactions do not appear.[1] Thus, he obtains the following equation:

$$m \frac{d^2u}{dt^2} du + m' \frac{d^2U}{dt^2} dU = e \nabla^2 u\, du - K\, U\, d\, U. \qquad (25).$$

Where u, U are displacements and e the rigidity of ether in free space. The notation is changed so as to make it uniform throughout this paper. Those equations he combines with a "second equation relating to the special mode of action of the matter particles which can be no other than the renowned fundamental equation of Bessel's theory of the pendulum." This[2] he writes:

$$m \frac{d^2u}{dt^2} C + m' \frac{d^2U}{dt^2} = - K\, U. \qquad (26).$$

These equations would apply for transparent media, and when absorption takes place terms are added for the reaction of the matter on the ether. The fundamental equations then become[3]

$$m \frac{d^2u}{dt^2} - m' \frac{d^2U}{dt^2} C = e \frac{d^2u}{dz^2} + b\, m'\, U + c\, m' \frac{dU}{dt} \qquad (27a).$$

$$\frac{d^2u}{dt^2} C + \frac{d^2u}{dt^2} = - K'\, U - g' \frac{dU}{dt} \qquad (27b).$$

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[1] Ketteler, Wied. Ann., XXI., p 201.

[2] Ketteler, ibid. XXI., p. 201; XVIII., p. 413.

[3] Ketteler, "Theoretische Optik," pp. 93-95.

Solving these, Ketteler finds:[1]

$$\mu_0^2 - X_0^2 - 1 = C\,\frac{m'}{m}\,\frac{\left(B\,\frac{\lambda^2}{\lambda^2_m} - C\right) G\,\frac{\lambda}{\lambda_m} - H'\,\frac{\lambda}{\lambda_m}\left(\frac{\lambda^2}{\lambda^2_m} - 1\right)}{\left(\frac{\lambda^2}{\lambda^2_m} - 1\right)^2 + G\,\frac{\lambda^2}{\lambda^2_m}} \qquad \text{(28a).}$$

$$2\mu_0\,X_0 = C\,\frac{m'}{m}\,\frac{\left(B\,\frac{\lambda^2}{\lambda^2_m} - C\right) G\,\frac{\lambda}{\lambda_m} - H'\,\frac{\lambda}{\lambda_m}\left(\frac{\lambda^2}{\lambda^2_m} - 1\right)}{\left(\frac{\lambda^2}{\lambda^2_m} - 1\right)^2 + G^2\,\frac{\lambda^2}{\lambda^2_m}} \qquad \text{(28b).}$$

A new phase was given to the subject in 1893 when Helmholtz[2] produced his theory of dispersion based upon the electromagnetic theory of light. He postulates charged bodies imbedded in an ether transmitting electric disturbances, and that the forces acting upon the ether during these disturbances can set the material particles in vibration. He follows the electrolytic theory in assuming that electric charges of definite magnitude are accumulated at the center of affinity of chemically combined ions, that these charges may be either positive or negative but always have the same absolute value for every center of affinity. "If the ether surrounding a pair of combined ions is traversed by electric forces and thereby dielectrically polarized, the oppositely charged ions will be subjected to stresses in the direction of the lines of force, that is, to two forces of equal magnitude but opposite in direction which together form a couple; this couple will not set the center of mass of the molecule in motion, but it will tend to lengthen or shorten the electrical axis of the molecule and to deflect it towards or away from the direction of the lines of force." The pairs of ions as used by Helmholtz possess mass and inertia in addition to the usual properties of dielectrically polarized molecules of insulating substances. Hence, oscillations may throw them out of equilibrium and produce variations in the electrical moments due to these ionic charges, f, g, h, forces, independently of the electrical moments per unit volume, *f*, *g*, *h*, forces, of the free ether.

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1 Ketteler, "Theoretische Optik," p. 100.

2 Helmholtz, Wied. Ann. XLVIII., pp. 389, 723; L. E. XXXVII., p. 404.

In the energy equation Helmholtz takes account of electrostatic, magnetic, electro-magnetic, and mechanical forces and derives equations representing each. Finally, he applies the Principle of Least Action considering variations to be present in f, g, h,, *f, g, h,* and F, G, H, and derives an expression for the refractive index.

Heaviside[1] criticizes several points, especially the term electro-magnetic energy, and the application of the Principle of Least Action.

Ketteler[2] has shown that the dispersion formula developed by Helmholtz, from the electro-magnetic theory, and the one published by himself, based on the elastic solid theory, can be expressed by the same equation.

$$\mu_0{}^2 - X^2 - 1 = \Sigma \frac{D\,\lambda^2\,(\lambda^2 - \lambda^2{}_m)}{(\lambda^2 - \lambda^2{}_m)^2 + g^2\,\lambda^2} \qquad (29a).$$

$$2\mu_0\,X_0 = \Sigma \frac{D\,g\,\lambda^3}{(\lambda^2 - \lambda^2{}_m)^2 + g^2\,\lambda^3} \qquad (29b).$$

Where μ_0 equals refractive index for wave length λ at perpendicular incidence.

Where X_0 equals extinction index for wave length at perpendicular incidence.

Where λ_m equals wave length in free ether of rays absorbed.

Where D equals a constant depending, in the elestic theory, upon the refractive index of infinitely long waves, and, in the electro-magnetic theory, upon the dielectric constant of the medium. These equations are usually termed the Ketteler-Helmholtz dispersion formula, and were tested by Pflüger[3] as described in the first part of this paper.

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[1] Heaviside, L. E. Vol. XXXVII., p. 470.

[2] Ketteler, Wied. Ann. XLIX., p. 382; LIII., p. 823.

[3] Pflüger, Ibid., LXV., pp. 173, 225.

PART II.

EXPERIMENTAL WORK.

The superiority of the optical surface of cyanin prisms, made by pressing together the fused crystals between glass plates, and the larger angles available lead one to suppose that more accurate determinations of the dispersion can be made with such prisms than with those obtained by the evaporation of alcoholic solutions of the dye. Of special theoretical interest are the values of the refractive indices for wave lengths within the absorption band. The results of the experiments give conclusive evidence of the continuity of the dispersion curve through the absorption band in the yellow and show the presence of a second absorption band in the ultra violet, beginning at wave length, 368 $\mu\mu$, which has not been heretofore observed and which should be taken into account in proving the Ketteler-Helmholtz dispersion formula.

The first part of the experimental work consisted of a systematic examination of all the available aniline dyes known to show anomalous dispersion with a view to determining:

1st. How many of them could be formed into prisms by the fusion method.

2nd. The precautions necessary for the formation of prisms of the best quality.

From Fuchsin, Aniline Green, Hoffmann's Violet, Uranin, and Aurine, prisms were made, but with difficulty. Their quality was, however, too poor to warrant any further work. The Uranin absorbs moisture from the atmosphere and dissolves if not protected. Acid Magenta, Erithrosene, Aniline Red, Rose Bengale, Genetian Violet, and Methyl Blue could not be made into prisms by this method. Cyanin fuses at about 116 °C, becoming a pasty substance for a few degrees and then a liquid of

a deep plum color and of the consistency of a rather thick syrup. The crystals when heated to about 80° C change color from a bright green to a golden brown. After fusing the cyanin rapidly evaporates and leaves a solid residue.

To secure good prisms the heating of the cyanin must be done rapidly, the prism formed, pressed, and cooled quickly and at the right temperature. If too cool, the fused mass can not be pressed into the required thinness; and if too hot, a number of small pin holes will appear, due to the gas bubbles formed. The pressure applied is also a factor that must be carefully adjusted if good results are to follow. This becomes very important when thin prisms are desired. For work in the transparent parts of the spectrum, prisms of 10′ to 20′ angle can be used, but in and near the absorption band they must be exceedingly thin to let any light through.

Cyanin being found to be the only dye from which wholly satisfactory prisms could be formed it was decided to limit the work to an examination of the dispersion of this single substance.

Four distinct methods have been employed, namely:

(a) Direct spectrometer readings in the visible spectrum, the slit of the instrument being illuminated with monochromatic light.

(b) Photographic records of the deviation of a system of monochromatic rays from a Rowland concave grating illuminated by an iron arc.

(c) A qualitative method based on Newton's principle of crossed prisms.

(d) Photographic records of the displacement of the fringes in the Michelson interferometer produced by thin films of cyanin.

(a) *The visible part of the spectrum.* The first method was employed by Wood:[1] A plan of the apparatus is shown in figure 3. Sunlight reflected from a heliostat (A) is concen-

* Phil. Mag. XLVI (1898), p. 380.

trated upon the slit of a large, direct vision spectroscope (C), the eye-piece of the latter being removed, and in its place is fixed the slit of a Geneva Society Spectrometer (D), the eye-

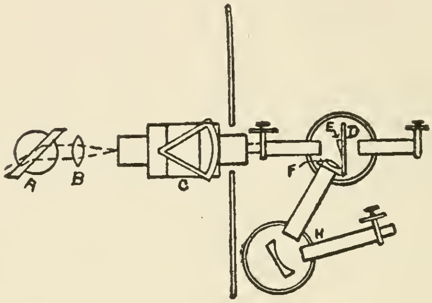

FIG. 3.

piece of which is provided with a filar micrometer. The glass plate on which the cyanin prism (E) had been formed was covered with black paper, in which two small apertures had been cut, one coming over the cyanin prism and the other slightly to one side of it. The latter, or clear aperture, gave a direct image of the slit of the spectrometer; the former, a deviated image, due to the bending of the rays by the prism. Both images being in the field of the telescope at once, the distance between them could be measured by the filar micrometer, and these readings when reduced to the circular scale, furnished the data from which the refractive indices were calculated. Any slight deviation due to the possible prismatic form of the glass plate used was thus eliminated. By turning a tangent screw, operating on the prism system of the direct vision spectroscope, the focused spectrum could be made to traverse the slit of the spectrometer, which was thereby illuminated with monochromatic light of any desired wave length.

To determine the wave length of the light corresponding to any particular reading of the cyanin prism the following methods were used. First, by opening the slit rather wide a considerable portion of the solar spectrum was allowed to enter the instrument in which the Fraunhofer lines were distinctly visi-

ble. Some line of known wave length was chosen and by narrowing the slit the spectrum was gradually cut down until only light in the immediate vicinity of the line remained. In those parts of the spectrum where no conspicuous and easily recognized line existed a different method was employed. Removing the prism and placing a small mirror in its place, the light was thrown on a Brashear reflection grating spectrometer (See H, Fig. 3). This instrument had previously been graduated and the readings for the principal Fraunhofer lines been taken in its fixed position, and, hence, the wave length of any light used could be determined.

The angles of the cyanin prisms were measured by the Geneva Society Spectrometer. The prism was placed with its refracting edge vertical and at the center of the circular table. Parallel rays (*a b*, Fig. 4) coming from the collimator are reflected from the glass plate in the direction *b d* and from the surface of

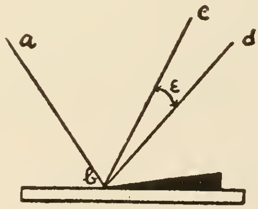

FIG. 4.

the prism along *b c*. The angle *e* between the reflected rays is twice the angle of the prism. For prisms of small angle both images of the slit were in the field of the telescope and the distance between them was measured by a filar micrometer. These readings were then reduced to the circular scale. For larger angles the readings were taken on the circular scale direct.

If A represents the angle of the prism and d the deviation, both in circular measure, the index of refraction is found by the usual formula:

$$\mu = \frac{\sin \frac{1}{2}(A + d)}{\sin \frac{1}{2} A} \qquad (30).$$

The angles of the prisms being very small, we can replace the sides of the angles by their circular measures, thus:—

$$\mu = 1 + \frac{d}{A} \qquad (31).$$

By this formula the indices given in Table VII were calculated.

Plate 16 shows graphically the contents of Table VII. The abscissæ are wave lengths in $\mu\,\mu$ units, while the ordinates are indices of refraction.

For three reasons the results are not so good in the absorption band as in the red and blue parts of the spectrum. These are:

1st. To transmit the yellow light the prisms must be very thin, and hence, of small angle. This increases the percentage error in measuring the angle of the prism as well as the deviation.

2d. The image of the slit made by the deviated ray was not as sharply defined in the absorption band as in the transparent parts, a diffraction haze appearing around the image due to the narrow portion of the prism through which the light could pass.

3d. Any slight error in measuring the wave lengths would affect the result to a larger degree in this portion of the curve than in the other parts.

Table VII.

Prism No. 1. Angle 17′ 3″.8.

λ	μ	λ	μ	λ	μ	λ	μ
765.0	1.920	479.8	1.387	463.7	1.434	434.2	1.524
759.0	1.970	479.2	1.387	461.0	1.449	429.5	1.535
735.0	1.985	475.6	1.416	456.8	1.460	427.0	1.533
703.5	2.050	475.3	1.401	451.8	1.479	419.1	1.544
688.7	2.131	472.7	1.408	441.2	1.496	410.8	1.537
685.6	2.150	470.0	1.418	438.0	1.523	406.5	1.553
486.7	1.380						

Prism No. 2. Angle 4′ 52″.8.

λ	μ	γ	μ	γ	μ
668.0	2.23	518.3	1.15	501.8	1.27
658.1	2.34	514.2	1.15	495.8	1.28
524.8	1.12	504.8	1.19	489.6	1.35

Prism No. 3. Angle 23′ 59″.7.

λ	μ
732.0	2.027
688.0	2.170

Prism No. 4. Angle 1′ 17″.2.

λ	μ
663.6	2.31

Prism No. 5. Angle 24″.7.

λ	μ	λ	μ	λ	μ	λ	μ
667.5	2.26	610.0	2.14	589.0	1.65	564.0	1.30
646.5	2.35	607.0	2.06	589.0	1.59	550.5	1.22
633.5	2.30	607.0	1.93	580.0	1.57	540.0	1.12
633.0	2.35	599.5	1.86	580.0	1.59	518.2	1.14
623.5	2.33	597.0	1.79	568.0	1.45	506.5	1.22
610 0	2.10						

TABLE VII — Continued.

Prism No. 11. Angle 32".7.

λ	μ	λ	μ	λ	μ	λ	μ
606.2	1.88	518.0	1.12	561 0	1.27	531.0	1.13
599.2	1.81	486.5	1.33	589.5	1.58	518.3	1.13

Prism No. 13. Angle 51".7.		Prism No. 14. Angle 21′ 3".8.	
λ	μ	λ	μ
622.8	2.25	723.6	2.014
589.5	1.67	723.6	2.020
		423.0	1.507

Prism No. 15. Angle 2′ 10".1.

λ	μ	λ	μ	λ	μ
733.0	2.01	655.5	2.32	469.0	1.40
683.0	2.19	502.0	1.24	451.0	1.51
672.0	2.25	486.5	1.37	441.0	1.50
657.0	2.32				

(b) *Investigations in the Ultra Violet.*—The dispersion having been measured visually with the spectrometer as far into the violet region as was possible, the photographic method employed by Pflüger[1] was adopted to extend the work into the ultra violet. The arrangement of the apparatus is seen in figure 5 except that sunlight was used instead of the light from the iron arc.

A solar spectrum thrown by a Rowland concave grating was received upon a photographic plate. Between the grating, E, Fig. 5, and the plate, F, was placed an opaque screen, H, provided with a rectangular aperture over which was fastened the glass plate supporting the cyanin prism. A strip of black pa-

[1] Pflüger, Wied. Ann. LXV., p. 206.

per, furnished with two small apertures, was mounted over the plate, one aperture exposing the prism, the other, clear glass. Thus, the light arrived at the sensitive plate by two paths, one direct and the other deviated by passing through the cyanin prism. Therefore, two sets of the Fraunhofer lines were found

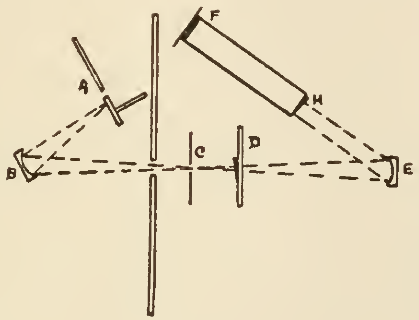

FIG. 5.

on the plate, of which two sample photographs are seen in plate 19, figures 1 and 2. The upper set of lines was formed by rays coming through the prism and the lower set by the direct path. For making these photographs the angle of the prism was 2′ 51.5″, the distance from the prism to the plate was 177.6 c. m., while the time of exposure for the direct ray was three minutes and for the other seven minutes.

The distance between a given line in one set and the corresponding line in the other set was measured by a filar micrometer attached to the eye-piece of a microscope. Let X be this distance in centimeters; let d be the distance from the plate to the prism in centimeters, and let α be the angle of the prism in seconds of arc, then the index of refraction for the wave length used is given by the following formula:—

$$\mu = 1 + \frac{X\ \overline{360}^{3}}{2\,\pi\, d\, \alpha} \qquad (32).$$

By this method the indices given in Table VIII, were calculated.

TABLE VIII.

λ	μ	λ	μ
422.7	1.530	....	....
410.0	1.565	380.0	1.60
404.0	1.573	372.0	1.61
395.0	1.606	....	....

These values of μ are indicated on Plate 16 by crosses and the values obtained with the spectrometer by circles.

To continue the work in the fall and winter, when cloudy weather made sunlight unavailable, an electric arc formed between an iron rod and a rapidly rotating iron disk, was substituted for the sunlight. The bright lines in the iron spectrum gave the same results as the Fraunhofer lines. With light of wave length shorter than 368 μ μ, passing through the cyanin prism, no effect could be produced on the sensitive plate although a five hours continuous exposure was made. To increase the intensity of light when passing through the cyanin, the prism was moved from H to D, eight centimeters behind the slit, C (Fig. 5).

With this arrangement of the apparatus photographs were taken and the results are shown in figures 3, 4, 5, and 6 of plate 19. Light coming by the direct path made the upper set of lines, while the part coming through the cyanin formed the lower set. In figure 3 the time of exposure for the upper set was forty seconds, and for the lower, seventy seconds. For the longer waves the intensity of the two sets of lines in this photograph is almost the same, but beyond 368 μ μ no lines appear in the lower set. The cyanin evidently absorbed the energy of wave lengths shorter than 368 μ μ. The presence of this absorption band in the cyanin and the approach to the absorption band in the glass beginning at 335 μ μ is seen in figure 4 of plate 19. The time of exposure in the photograph of the latter, by the direct ray, was forty seconds, and through the cyanin five minutes.

To show the similarity between this effect and the action due to the absorption in the green, figures 5 and 6 of plate 19 were taken. In the former the time of exposure for the direct ray was forty-five seconds and for the cyanin five minutes. This gives approximately the same intensity for the lines of shorter wave length in the photograph, but for the longer wave no impression is seen in the lower band. Figure 6 is the same as figure 5 save the time of exposure, which in this case was forty seconds for both sets. By comparing the wave lengths with the absorption curve it is seen that the photographs of figures 5 and 6 are at the edge of the absorption band in the yellow.

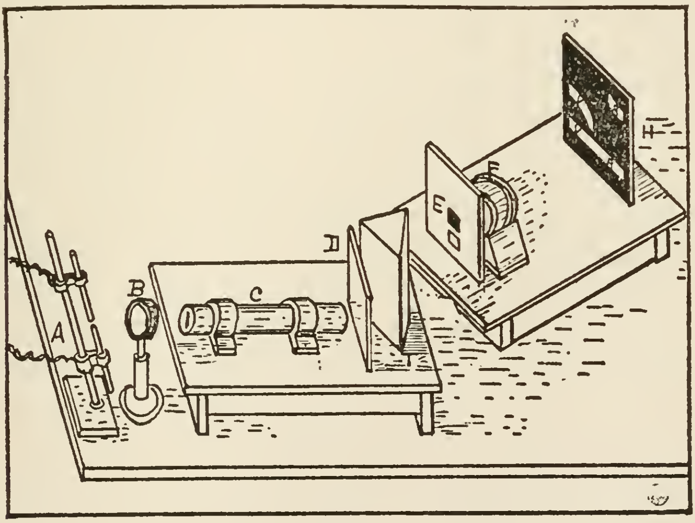

FIG. 6.

(c) *The Method of Crossed Prisms.*—In Newton's method of crossed prisms we have a beautiful means of showing the phenomenon of anomalous dispersion, for by it we can bend a straight, continuous spectrum into a curve identical in every respect with the dispersion curve obtained by measurements with the spectrometer. The method was used by Kundt in the course of his investigations on anomalous dispersion. This method furnishes qualitative data only, but the fact that the curve of dispersion is directly photographed gives value to the results. The general arrangement of the apparatus is seen in figure 6.

The light of an arc lamp, A, was focused on the slit of the spectrometer, C, and parallel rays coming from the collimator passed through a water prism, T, and falling on an achromatic lens, F, of long focus (a telescope lens of six feet focus) formed a sharply defined spectrum, V—R, on the photographic plate, H. In front of the objective, F, was placed a cyanin prism, E, with its refracting edge *horizontal* and turned down. This prism deviated all the rays *upwards* before they entered the lens, F, thus elevating the image on the photograph. Since the deviation is due to the fact that light is transmitted slower in cyanin than in air, and that the velocity of transmission is a function of the wave length, therefore, the elevation of light of any wave length will be proportional to $\mu - 1$ where μ is the index of refraction for the given wave length. Consequently, if the spectrum produced by the water prism is considered to be normal then the crossed prism spectra produced by the cyanin prism as described above, is a curve identical in every respect with the curve of dispersion calculated by the direct spectrometer method and shown graphically in the curve of plate 16. Erythro plates were used and the more intense action of the blue and violet was modified by the introduction of an Aurantia color screen or filter, D. In this way fully exposed photographs were obtained of the dispersion curve from the extreme red to the violet. The results are seen in figures 1–6 of plate 20. For figure 1 the lower straight band was made by a direct exposure, while the curved strips above are parts of the same spectrum after having passed through the cyanin prism. The angle of the prism was 17′ 1.0″, and the time of exposure, by the direct path, was twenty seconds, while through the cyanin it was one hour. The yellow part of the spectrum is absent, the prism absorbing all the energy of this wave length. For figures 2 and 3, the same method of procedure was pursued, and these photographs are inserted to show the effect of the Aurantia color screen, D. The angle of the cyanin prism used for these photographs was 17′ 3.8″. For figure 3 no screen was employed; for figure 1 the light was passed through a screen of medium thickness, while for figure 2 a rather dense filter was used. The haze

appearing in figure 3, where no color screen was used, is entirely absent in figures 1 and 2, while the form of the curve is apparent in all. Cyanin has a very strong absorption band in the yellow, and to let any light through in this part of the spectrum very thin prisms must be used. In figure 4 of the same plate is seen a photograph of a crossed prism spectrum when the cyanin prism was thin enough to let light of all wave lengths pass through. The refracting angle was only 24.7″, so the deviation is small, but the continuity of the curve is evident. No exposure was made by the direct path to avoid overlapping of the two spectra. A photograph of a similar continuous crossed prism spectrum for a cyanin prism of 2′ 51.6″ refracting single, is seen in figure 5 of the same plate, in which the deviations are proportionally larger than in figure 4, and the form of the curve can easily be followed through the absorption band. In figure 6 the results are seen of four successive exposures through a cyanin prism of 28′30″ refracting angle. The great dispersive power of the dye is apparent and although the yellow is absent the rest of the curve agrees very well with the dispersion calculated by direct spectrometer readings. The haze in the green is due to diffraction; the angle of the prism was so large that only a very narrow edge was transparent to the green and this produced the ordinary narrow aperture effect.

(d) *The Interferometer Method.*—The previous work has for its basis the deviation of a beam of light by a cyanin prism. The index of refraction can also be found by measuring the retardation produced by a thin film. To make uniform films of cyanin the crystals were dissolved in absolute alcohol and the resulting solution filtered. This solution was then kept in an air-bath at a temperature between 35° and 40° C. Pieces of plate glass, after being carefully cleaned and heated to the same temperature, were dipped into the solution, and placed on edge to dry in the air-bath. The thickness of the film depends on the concentration of the solution, and as the alcohol evaporates rapidly in the air-bath, films of continually increasing thickness are obtained by dipping in fresh plates from time to time.

To secure good films it is important to use "absolute" alcohol and to keep the temperature inside the given limits throughout the operation. The retardation produced by the film was measured with a Michelson interferometer (F of figure 7), photographs being made of the displaced fringes. The interferometer was illuminated with monochromatic light obtained from the direct vision spectroscope, C, as described in the first part of this paper. From one-half of one of the coated glass plates the cyanin film was carefully removed, the remainder of the film having a straight edge down the center of the plate. This plate, H, was placed between the movable mirror, M, of the interferometer and the half silvered plate, P, with the straight edge of the cyanin film vertical, the instrument having been previously adjusted for horizontal fringes. A plate of clear glass, K, of thickness equal to that of the coated plate was placed in front of the other mirror, L, of the interferometer as a compensator.

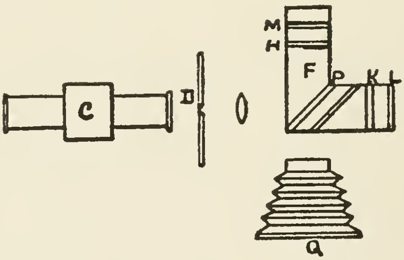

FIG. 7.

The fringes formed by the interference of rays coming through the cyanin were displaced relatively to those formed by rays coming through the clear portion of the plate. In order to facilitate the determination of the displacement the fringes were photographed by means of a camera at Q. The camera was so arranged that by moving the back portion slightly, successive exposures could be made on the same plate, showing the relative displacements of the fringes for all values of μ from the extreme red to the ultra violet.

Since the retardation is a function of the wave length, the dis-

placement between the two sets of fringes varies when the wave length of the light used is changed. The light passing through the slit, D, was changed systematically for the successive exposures, so that in the series of photographs shown on plates 21 and 22 a complete record of the retardation throughout the spectrum is secured.

The film (No. I), used in preparing the series shown in figure 1 of plate 21, was very thin (about .00012 mm.) and perfectly transparent throughout the absorption band. The white mark on the sides of the fringe systems was made later to show which pair of fringes belong together. The number given below each exposure is the wave length in $\mu\,\mu$ units of the light used in each case.

The series given in figure 2 of plate 21 shows the retardation produced by a somewhat thicker film (about .00017 mm.) not quite as transparent in the region of the absorption band as the first. The third film (No. III), used in the preparation of the first figure of plate 22, was much thicker (about .00071 mm.) and quite opaque for yellow or yellowish green light. Consequently, no fringes were formed in this part of the spectrum by the light passing through the cyanin film.

To continue further into the ultra-violet a Rowland grating was substituted for the spectroscope. Using film No. II, a new series was taken on the blue, violet, and ultra-violet, the results being shown in the second figure of plate 22. Repeating the same series and using film No. III, the photograph shown in figure 3 of the same plate was obtained.

In these photographs it is to be noticed that beyond $\lambda = 345.6$ no fringes appear. This is due to the absorption of shorter waves by the glass. Further, below $\lambda = 374.2$, the intensity of the fringes in both halves of each exposure is practically the same, showing that the cyanin film in this part of the spectrum was perfectly transparent. Between these lines, $\lambda = 374.2$ and $\lambda = 345.6$ that part of the light which had the cyanin film in its path is much fainter for the larger waves and disappears altogether before reaching the absorption band in the glass. This corroborates previous observation and proves

conclusively that cyanin has an absorption band in the ultra-violet.

To calculate the refractive index from the photographs shown on plates 21–22, it is necessary to know which pair of lines belong together. With monochromatic light it is impossible to tell whether the displacement is half a fringe or one and a half, or any number of whole fringes more, but if white light is employed and both paths are of equal length there appears a central dark fringe, bordered by about a dozen colored fringes similarly placed with reference to the central dark fringe. This dark fringe is the only one in the whole system that can be identified. Substituting white light in front of slit, D, and having film No. I, on the path of the interferometer, a photograph was taken. The result is shown in *a* in figure 7 of plate 20. When looking at the fringes direct it was plain that the fringes marked on the photograph belonged together. Using film No. II, a photograph seen in *b*, figure 7 (plate 20) was taken. The photograph does not show very plainly which pair of lines go together, but by looking at the fringes directly with the colors present those marked in the figure were easily determined to be part of the same fringe. The third exposure *c* in the same figure was taken with film No. III in the interferometer. The strong absorption of this film made the resulting figure hard to distinguish so that even when the colors were seen directly, it was difficult to tell which was the central dark fringe in the part passing through the cyanin. Several observers, however, independently judged the pair marked in the figure to be correct.

The index of refraction can be found by the usual formula for thin films:—

$$\mu = 1 + \frac{n\,\lambda}{2\,e} \qquad (33).$$

where μ is the index for wave length λ, n, the number of fringes by which the central fringe is displaced, and e, the thickness of the film. The measurement of e is difficult and the percentage error is large when a film is very thin, as is the case in

these experiments. Therefore, it is desirable to secure a ratio between the indices for the different wave lengths and find the index for some one wave length by another method.

Let μ equal index of refraction for λ.

Let μ_1 equal index of refraction for λ_1.

Let n equal displacement of fringes for wave length λ in terms of that same wave length.

Let n_1 equal displacement of fringes for wave length λ_1 in terms of that same wave length.

Then: $n \lambda_1 : n \lambda_1 :: \mu - 1 : \mu. - 1.$

Solving for μ_1 :

$$\mu_1 = 1 + \frac{(\mu - 1)\, n_1\, \lambda_1}{n\, \lambda} \qquad (34).$$

This method is advantageous when the indices for portions of the spectrum, as in the absorption band for cyanin, are difficult to measure by other methods. The displacements n on the photographs were measured by means of a filar micrometer attached to an eye-piece magnifying about twenty diameters.

Column a in Tables IX–XII gives the width of a fringe, for the given wave length, on the photograph in terms of divisions on the micrometer screw. The width of the displacement in the same units is given in column b. Hence $\frac{b}{a}$ equals n, the displacement in terms of fringes of the wave length used.

TABLE IX.

λ	a	b	n	$n\lambda$	μ
705.5	166.0	82.0	.494	349	2.02
669.5	160.8	100.4	.624	418	2.21
654.9	154.3	103.2	.670	439	2.28
640.1	152.7	107.8	.706	452	2.31
625.8	151.7	104.8	.690	430	2.25
613.2	179.0	84.7	.576	353	2.03
599.8	145.6	74.0	.506	306	1.89
589.6	144.0	59.3	.412	243	1.71
579.0	141.4	52.0	.368	213	1.62
569.5	137.4	42.3	.307	175	1.51
560.7	136.0	28.0	.206	115	1.33
552.4	133.0	24.8	.186	103	1.30
536.9	129.8	12.6	.097	053	1.15
523.3	127.1	16.0	.125	066	1.19
511.0	124.6	20.0	.164	068	1.25
500.0	122.6	28.6	.233	117	1.34
490.5	119.5	33.5	.280	137	1.39
480.9	117.4	34.2	.291	141	1.41
473.6	115.6	37.6	.326	154	1.45
466.1	113.9	39.8	.349	163	1.47
460.5	113.2	40.2	.355	165	1.48
453.0	111.5	42.6	.381	173	1.50
445.0	110.1	44.0	.399	178	1.52
433.0	107.3	48.0	.447	194	1.55
422.9	103.0	51.0	.495	209	1.59
414.8	101.6	51.8	.501	211	1.61
409.1	100.4	52.0	.518	212	1.62
399,8	97.9	52.2	.533	213	1.62
394.5	98.0	52.4	.535	213	1.62
892.1	97.7	54.0	.551	216	1.63

TABLE X.

λ	a	b	n	$n\lambda$	μ
492.5	129.9	36.6	.281	142	1.39
464.8	119.9	48.6	.405	142	1.52
436.5	110.5	49.2	.443	194	1.54
407.8	106.5	60.2	.565	230	1.62
380 0	101.8	63.2	.620	235	1.65
374.2	99.3	67.8	.701	262	1.70
368.5	97.5	70.0	.718	264	1.73
364.6	96.9	71.0	.732	267	1.74
362.7	96.1	72.1	.750	271	1.75
357.5	92.6	73.0	.770	275	1.76

The two photographs used for tables IX and X were taken with the same cyanin film in one path of the interferometer. The relation between μ and λ as given in tables IX and X is shown graphically in the curve of plate 17 by the full line, while the dispersion curve obtained by direct spectrometer readings is indicated by the broken line. These curves, obtained by entirely independent methods, agree very well, and the difference is probably due to a change in the properties of the substance in the two conditions, for the cyanin was fused in the one case and deposited from an alcoholic solution in the other. It is important to note the rapid rise in the curve when the absorption band in the ultra violet is approached, as it shows a similarity to the increase in the refractive index as the absorption band in the yellow is approached from the red end of the spectrum.

The results from measurements made on the photograph shown in figure 1 of plate 22 are given in table XI.

TABLE XI.

λ	a	b	n	$n\lambda$	μ
705.5	196.0	442.0	2.26	159	2.11
669.5	182.2	489.2	2.68	179	2.25
654.9	177.1	517.4	2.92	191	2.34
640.1	173.4	538.0	3.10	198	2.38
523.3	143.7	82.8	0.576	301	1.21
511.0	138.0	114.0	0.826	422	1.29
500.0	135.6	135.3	0.996	498	1.35
490.5	134.6	151.6	1.125	553	1.38
480.9	129.6	160.6	1.239	596	1.42
473.6	125.0	161.4	1.290	611	1.43
466.1	124.6	169.2	1.357	632	1.44
460.2	124.4	173.0	1.424	655	1.46
453.0	125.2	185 4	1.480	671	1.47
445.0	126.0	188.0	1.480	664	1.47
443.0	123.3	194.0	1.570	697	1.49
422.9	116.4	197.0	1.687	713	1.50
444.8	114.0	201.0	1 760	731	1.51
409.1	110.0	204.0	1.930	770	1.54
394 3	105.0	207.4	1.970	778	1.55
392.1	104.9	213.2	2.030	795	1.55

For figure 2 of plate 22 the readings and calculated results are given in table XII.

TABLE XII.

λ	a	b	n	$n\lambda$	μ
492.5	144.7	197.8	1.36	672	1.40
464.8	132.3	224.6	1.69	789	1.47
436.5	119.2	241.6	2.02	882	1.53
407.8	113.6	245.2	2.16	880.	1.53
380 0	111.6	254.2	2.28	865.	1.52
374.2	109.9	257.6	2.29	857.	1.52
368.5	107.4	262.0	2.44	899.	1.54
364.6	105.5	266.0	2.52	923.	1.55
362.7	104.2	269.9	2.59	940.	1.56

The two photographs used for tables XI and XII were taken when cyanin film No. III was in one path of the interferometer. The relation between μ and λ, as given by tables XI and XII, is shown graphically by the line in plate 18, while the broken line represents the results obtained by direct spectrometer readings. The fringes in figure 1 of plate 22 are not quite parallel, and hence the errors in measuring a and b are larger, therefore the results for this film are not as good as for film No. II.

Conclusion.—It was originally intended to attempt a more rigorous proof of the Ketteler-Helmholtz dispersion formula, by using more accurately determined values of the refractive indices of cyanin for waves of various lengths. Pflüger's work while confirming the formula for the visible part of the spectrum, showed discrepancies in the ultra violet and extreme red. He suggests that these discrepancies, at least in the ultra violet, may be caused by the presence of an ultra violet absorption band. This band has unquestionably been found, but until its characteristics have been more thoroughly determined (a matter requiring a large amount of further experimental work) any attempt to apply the new values to the formula would be useless.

The most important results which have been obtained by this work may be summarized as follows:

1st. A fairly accurate determination of the dispersion curve for cyanin from the extreme red well into the ultra violet.

2d. The conclusive evidence furnished by the photographs taken with the interferometer, of the continuity of the curve through the absorption band of cyanin.

3d. The discovery of a new absorption band in the ultra violet spectrum of cyanin, the character of which will have to be accurately determined before any conclusive proof of the Ketteler-Helmholtz dispersion theory can be furnished by measurements upon this substance.

This work was undertaken two years ago, at the suggestion of Professor R. W. Wood, and is a continuation of a series of

experiments made by him in the previous year. The experiments have been performed under his direction, and I take this opportunity to acknowledge indebtedness to him for many ideas and suggestions and for much assistance.

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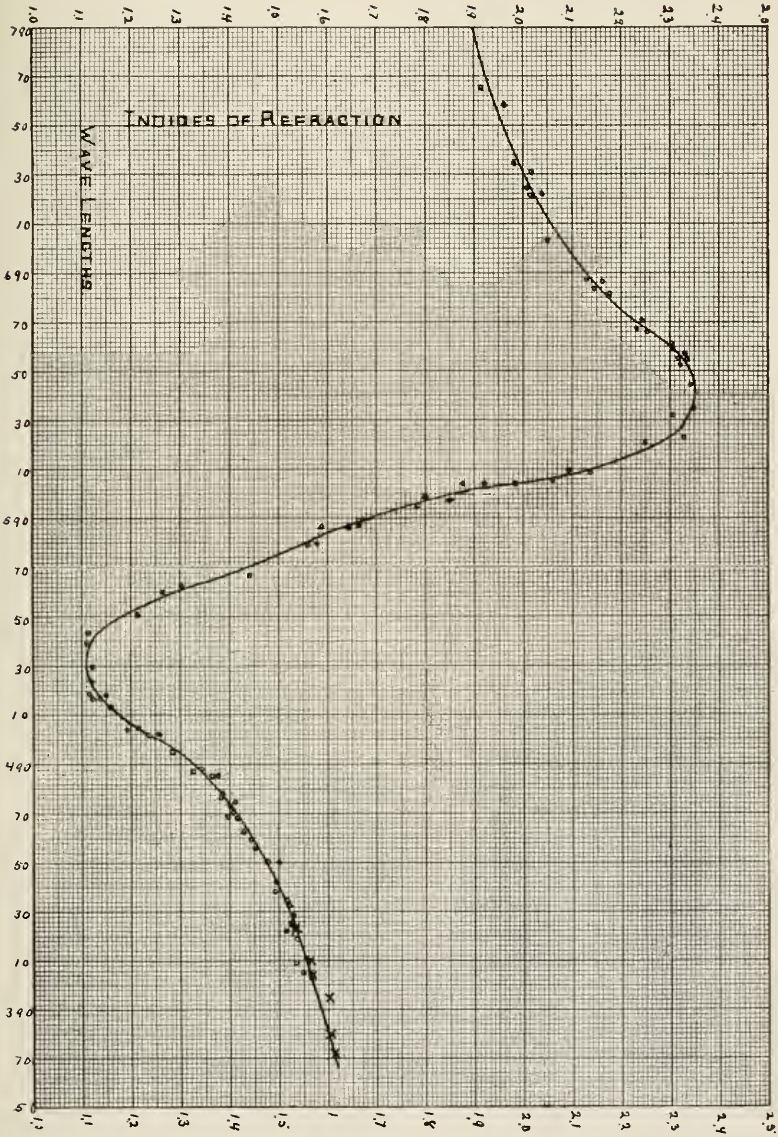
PLATES.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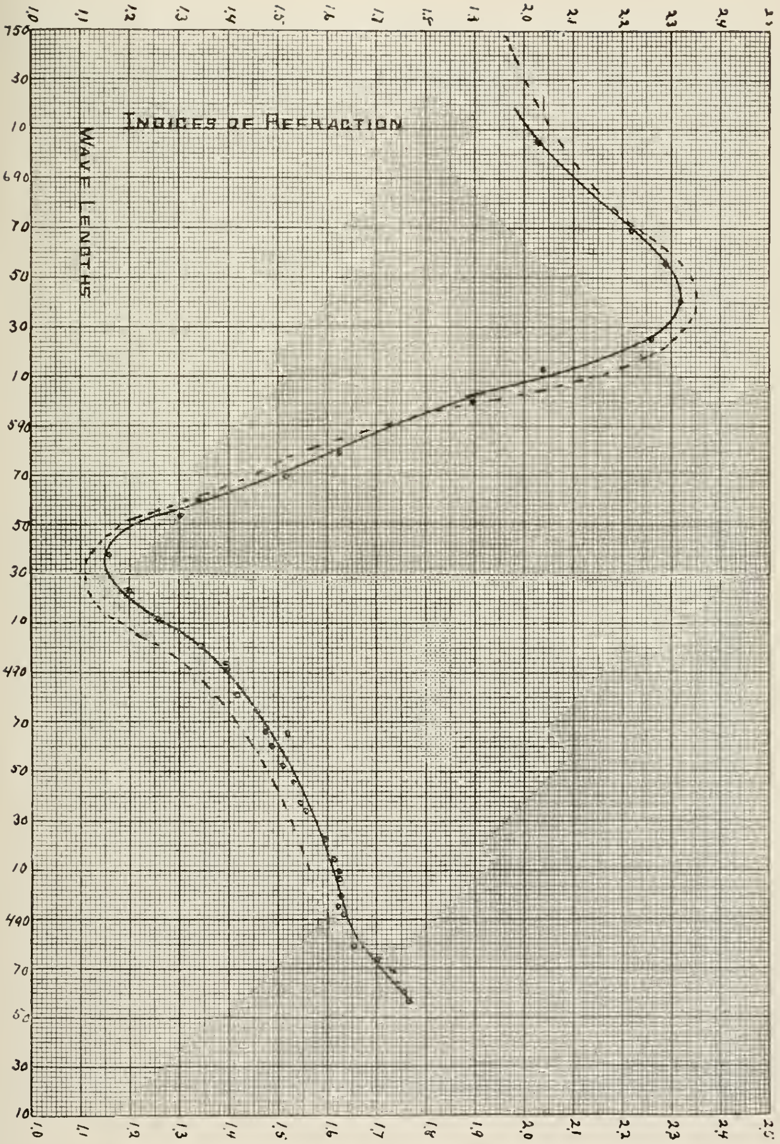
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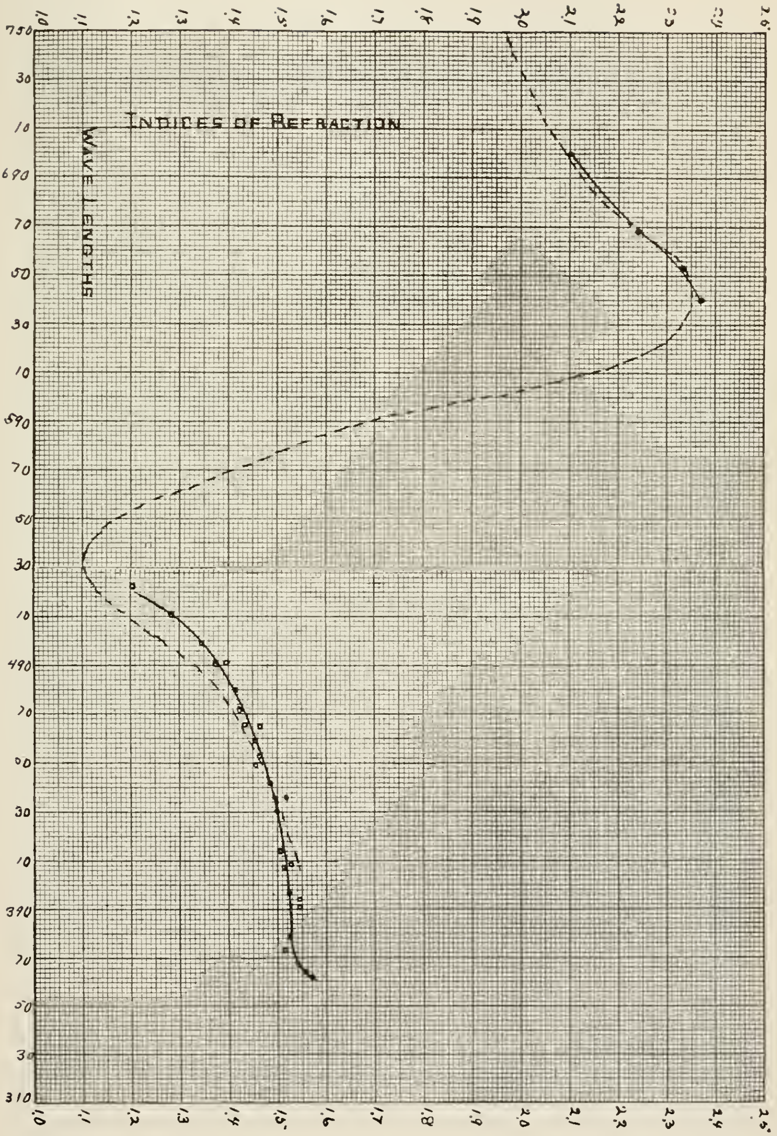
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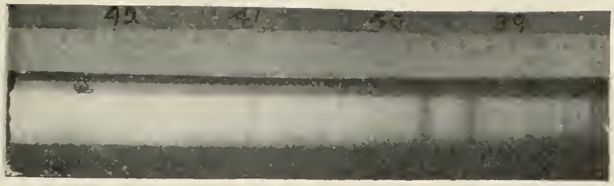

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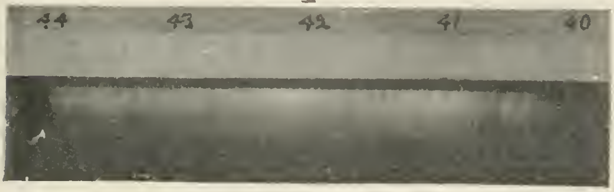

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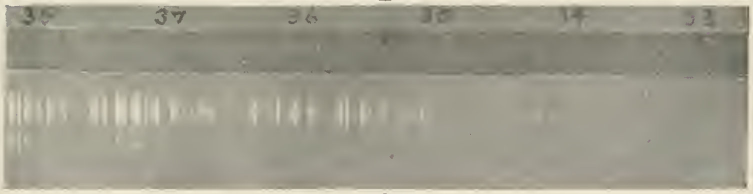

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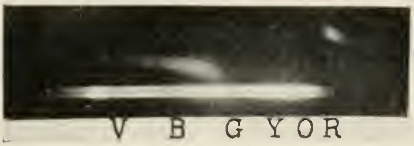

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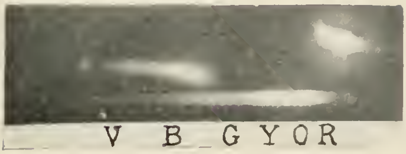

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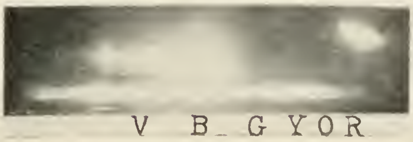

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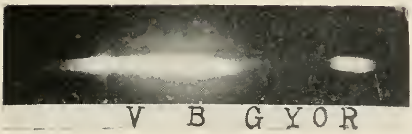

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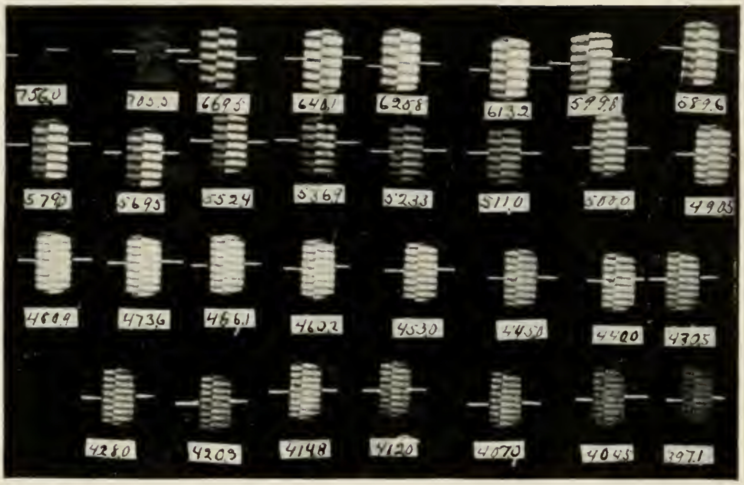

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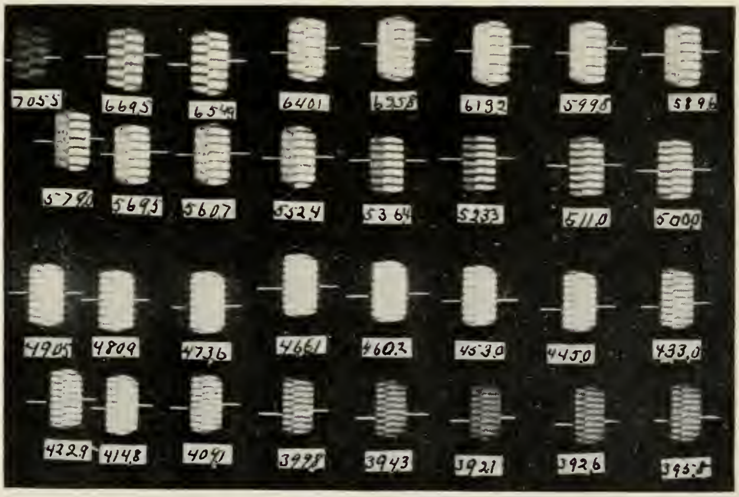

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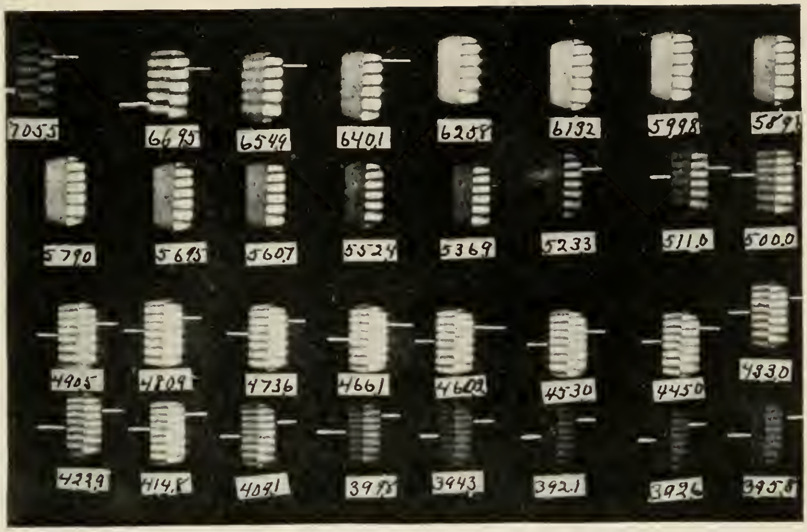
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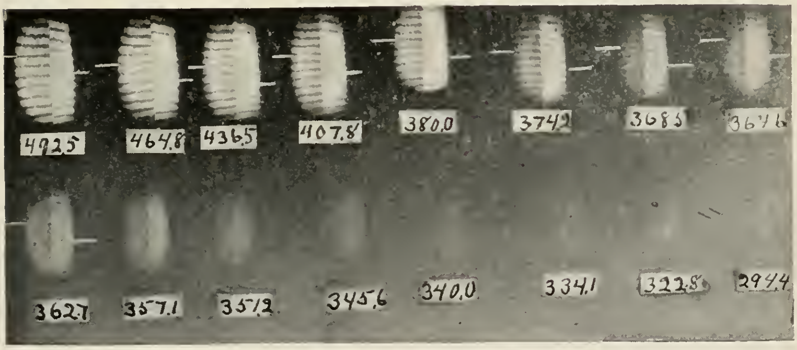
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BULLETIN OF THE UNIVERSITY OF WISCONSIN

NO. 47

SCIENCE SERIES, VOL 2, NO. 5, PP. 297-351

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BY

LOUIS KAHLENBERG, M. SC., PH. D.,
Professor of Physical Chemistry.

WITH THE CO-OPERATION OF

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THE THEORY OF ELECTROLYTIC DISSOCIATION AS VIEWED IN THE LIGHT OF FACTS RECENTLY ASCERTAINED.

Introduction.

The theory of electrolytic dissociation, as advanced by Arrhenius[1] in 1887, is based primarily upon the facts that the molecular conductivity of solutions increases with the dilution; that substances which when dissolved conduct electricity also have abnormally low molecular weights in such solutions when tested by osmotic or freezing- or boiling-point methods; and that the so-called degree of dissociation may be calculated from the electrical conductivity, or the results of the molecular weight determinations. In his original article Arrhenius states that the phenomena of electrolysis when viewed from the standpoint of thermodynamics, require the assumption of the presence of free ions, as was pointed out by Clausius, and that the heats of neutralization of acids and bases in dilute solutions and the various physical properties of salt solutions, which are well known to be additive in character, support the electrolytic dissociation hypothesis. The effect which the publication of that memorable article of Arrhenius had, need not be dwelt upon at length here. Suffice it to recall that its author sought to save van't Hoff's theory of solutions from having but a limited application, and at the same time to bring into correlation facts that had hitherto been entirely isolated. Chemists and physicists alike were astonished by the audacity of the assumption

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[1] Zeit. Phys. Chem. 1, 629 (1887).

made by this investigator of recognized ability. The theory at once met with great opposition, notably in England, and it was by no means received with open arms on the continent. But the hypothesis inspired experimental investigation, and the results of this phenomenal activity (which at first centered in Ostwald's laboratory at Leipzig, but spread rapidly to other parts of Germany, to various other countries of Europe and to America) soon silenced opposition in Germany and gradually diminished the opposition in England. It must not be supposed, however, that this silence meant that all were convinced. The silence seemed to result on the one hand because of a recognition of the futility of the debate with the knowledge of existing facts, and because of a recognition of, if not an admiration for, the enthusiasm displayed by the adherents of the theory,—enthusiasm that bore fruitful results in experimental investigations of various physical, chemical, and physiological properties of solutions, which results were ingeniously interpreted in the light of the new theory.

It was at first only in the case of aqueous solutions of the ordinary acids, salts, and bases that van't Hoff's theory of solutions met its difficulties; and when Arrhenius pointed out that these solutions are conductors of electricity, and assumed that the dissolved substances are electrolytically dissociated into free ions, these solutions were on this basis shown to support the theory. Arrhenius calculated the troublesome factor i (which van't Hoff had found it necessary to introduce to make the behavior of the above mentioned solutions conform to the gas equation) from the electrical conductivity on the one hand and from molecular weight determinations on the other, the resulting figures showing an agreement to within 5 to 15 per cent., according to his estimation. In view of the few experimental data at hand in 1887 and the fact that many of them had not been determined with accuracy, the poor agreement of a goodly number of values at least was readily overlooked in view of the generalities that the theory sought to bring, generalities which were soon incorporated without proper qualifications into text-books. The electrolytic solutions with which Arrhenius made his compari-

sons and deductions were without exception aqueous solutions. The non-aqueous solutions known at that time were practically non-conductors of electricity, and in dilute solutions at least they generally conformed fairly well in their behavior to van't Hoff's theory of solutions. Indeed, it was not until Raoult began his famous work on the freezing-points of non-aqueous solutions that it was discovered that molecular weights could be calculated from the lowering of the freezing-point.

In view of the facts then known, the idea gradually gained ground in the minds of those holding van't Hoff's theory and Arrhenius' auxiliary hypothesis concerning the nature of electrolytes, that non-aqueous solutions in general yield "normal" molecular weights for the solutes, and that they are "of course" non-conductors of electricity. This notion took root with surprising rapidity and the natural result was that investigations of electrical conductivity, of electromotive forces and of electrolysis in non-aqueous solutions were entirely neglected.[1] When in 1895 I had the great privilege of working in the inspiring atmosphere of Ostwald's laboratory, I upon one occasion asked the genial director of the institute why the electrical conductivity of non-aqueous solutions was not studied, the reply received was, *"Die nicht wässerigen Lösungen leiten ja nicht."* So it was hardly a surprise when in 1899 the new edition of Ostwald's *Grundriss der allgemeinen Chemie* appeared containing on pages 390 and 391 the sweeping, unqualified, italicized statement,

"Jedesmal wenn ein gelöster Stoff von den Lösungsgesetzen in solchem Sinne abweicht, dass sein osmotischer Druck (oder die diesem proportionale Gefrierpunkts- oder Siedepunkts-ändrung) grösser ist, als seinem Molekulargewicht entspricht, so zeigt er auch elektrolytische Leitfähigkeit und umgekehrt."

It is to be noted that Reychler's book on physical chemistry—a much less compendious volume, the English translation of which appeared early in 1899—nevertheless contains a very fair

[1] On the other hand it was at once assumed that free ions exist whenever a substance conducts electricity with accompanying chemical decomposition, be that substance a gas, a molten salt, or a solid.

consideration of the work that had at that time been accomplished in the study of non-aqueous solutions.

Behavior of Non-Aqueous Electrolytic Solutions.

Before entering upon the experimental part of this paper, I desire to call attention briefly to the import of some of the work on non-aqueous conducting solutions as bearing upon the theory of electrolytic dissociation. In the first place many cases have been found in which the molecular conductivity decreases with increased dilution. This is true for instance of solutions of NaI and NaBr in benzonitrile,[1] of $AgNO_3$ in piperidine[2], of $FeCl_3$ in pyridine,[3] of $FeCl_3$ in benzaldehyde[3] and of CoI_2 in $POCl_3$[4]. In other cases the molecular conductivity at first increases and then again decreases with the dilution, as, for instance, in solutions of $FeCl_3$ in paraldehyde,[3] of CBr_3 COOH in $POCl_3$[4]. Again many solutions have been found in which the solute according to molecular weight determinations is undissociated, and which nevertheless possess excellent power of conducting electricity. So $AgNO_3$ has a normal molecular weight[5] in pyridine and benzonitrile, and yet it conducts[6] fairly well in these solvents. According to Dutoit and Friderich[7] CdI_2, LiCl, NaI, $HgCl_2$, and NH_4CNS have normal molecular weights in acetone and yet these solutions are conductors of electricity. Walden[8] has found that KI, NaI, RbI, NH_4I and KCNS conduct well in liquid SO_2 and yet have abnormally large molecular weights in this solvent; while $S(CH_3)_3I$, $N(CH_3)_4I$ have molecular weights in this solvent which hardly differ from the theoretical more than do the molecular weights of non-electrolytes examined in SO_2. Walden himself says concerning this:

"Ganz unerwartet ist jedoch die doppelte Molekulargrösse für die

[1] Euler, Zeit. Phys. Chem. 28, 619 (1899).
[2] Lincoln, Jour. Phys. Chem. 3, 457 (1899).
[3] Kahlenberg and Lincoln, Jour. Phys. Chem. 3, 12 (1899).
[4] Walden, Zeit. anorg. Chem. 25, 213 (1900).
[5] Werner, Zeit. anorg. Chem. 15, 1 (1897).
[6] Kahlenberg and Lincoln, l. c.; also Lincoln, l. c.
[7] Bull. Soc. Chim. (Paris) (3) 19, 334 (1898).
[8] Ber. deut. Chem. Ges. 32, 2862 (1899).

elektrolyte 4–7, was ganz aus dem Rahmen des Geforderten herausfällt und nicht ohne Weiteres mit der üblichen Auffassung vereinbar ist".

Franklin and Kraus[7] have found that while NH_4NO_3, $NaNO_3$, and KI dissolved in liquid ammonia are excellent conductors of electricity, the boiling-points of the solutions, like those observed by Walden in SO_2, are not nearly as high as they ought to be on the assumption that electrolytic dissociation takes place. Again lately Nicolo Castoro[1] found by means of the freezing-point method that $AgNO_3$, $CdCl_2$, $HgCl_2$, and $ZnCl_2$ have normal molecular weights in urethane. I have made a few preliminary tests on the first three of these salts which show that their solutions in urethane are conductors of electricity. Very recently Innes[2] found the molecular weights of succinic, salicylic, and tartaric acids to be normal in pyridine, according to the boiling-point method. These acids undoubtedly form salts which re-dissolve in the excess of the solvent. Preliminary tests have assured me that all three of these solutions are fairly good conductors of electricity. The tartaric acid solution conducts best, as might have been expected.

While in many cases the molecular conductivity of non-aqueous solutions increases with the dilution, this increase is generally relatively slight. It has generally been impossible to calculate the degree of dissociation of substances in non-aqueous solutions from the conductivity, because in these solutions the molecular conductivity commonly either diminishes with the increase of dilution, or it increases slightly with the dilution, exhibiting no tendency to reach a maximum, or it remains practically constant, or soon reaches a maximum with so low a value that completeness of dissociation can not consistently be assumed. These facts will become evident to the reader by a perusal of the figures contained in the original articles above cited. I have already discussed at some length the difficulty of calculating the degree of dissociation in non-aqueous solutions,[3] and shall therefore simply add here that the calculation of the

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[1] Gaz. chim. Ital. 28 II, 317 (1898).
[2] Jour. chem. Soc. London 79, 261 (1901).
[3] Jour. Phys. Chem. 3, 395 (1899).

degree of dissociation from molecular weight determinations is in the case of non-aqueous solutions also impracticable, because the molecular weights are, as a rule, normal, or greater than normal, in spite of the fact that the solutions conduct well and that the boiling-point constant of the solvent is so high that dissociation certainly ought to be indicated, if present.

It is a well known fact also that molecular weights determined according to cryoscopic or ebullioscopic methods at times increase with the dilution; again, at other times, they do not change much with the dilution; and at still other times they decrease as the dilution increases. The latter behavior only is in harmony with the theory of solutions and the theory of electrolytic dissociation. Furthermore simple substances occasionally show abnormally low molecular weights and yet their solutions are not conductors of electricity. This I have found to be true, for instance, in the case of solutions of diphenylamine in methyl cyanide,—results as yet unpublished.

The osmotic theory of the galvanic cell, which uses the dissociation hypothesis as a basis, also naturally meets great difficulties when applied to chains containing non-aqueous solutions.[1]

In the face of these facts the theory of electrolytic dissociation is untenable in the case of non-aqueous solutions. While chemists have frequently in conversation admitted this to be true, I have also often been told, "But in the realm of aqueous solutions the theory concords with the facts so well". This led me to investigate the behavior of aqueous solutions somewhat further.

Experimental Part.

The general plan of the investigation was to determine the boiling-points of aqueous solutions of typical, common chemical compounds from low to very high concentrations, in order to see how the molecular weight changes with the concentration, and at the same time to measure the electrical conductivity of such solutions at or near their boiling-points. This would enable one to make much more accurate comparisons between the values of the degree of dissociation as calculated from conductivity and

[1] See Kahlenberg, Jour. Phys. Chem. 3, 395 (1899). Ibid. 4, 709 (1900).

molecular weight than by the but too common practice of comparing dissociation coefficients deduced from conductivity results obtained at room temperature, with those reckoned from boiling- or freezing-point experiments. The work of making the conductivity measurements at high temperatures and the corresponding boiling-point determinations was undertaken by Mr. Arthur A. Koch, to whose diligence and care the numerous tables (2 and 12 to 31, inclusive) given below are due. Again it was part of the plan to measure the conductivity of such solutions at 0° and at the same time to make molecular weight determinations by the cryoscopic method, and then to compare the degrees of dissociation found according to the two methods.[1] All the conductivity determinations at 0° were made by Mr. Roy D. Hall, the results of whose work are contained in Table 1 below.

The conductivity determinations were made by means of the usual Kohlrausch method, a telephone being employed. An Arrhenius resistance cell was used for the dilute solutions, and a U shaped cell with plantinized electrodes sufficiently far apart was employed for the concentrated solutions. All of the solutions were carefully made up to the proper volume at the temperature indicated. The measurements at 0° were made in a bath of melting ice surrounded by another very large bath of the same nature. In the immediate vicinity of the resistance cell a delicate thermometer was kept which remained very constant at 0°. At first it was attempted to measure the conductivity of solutions at 100°, but it was soon observed that small gas bubbles are so apt to form on the electrodes at this temperature as to introduce considerable error. It was found that at 95° this particular difficulty is not so prominent, and so the con-

[1] But few conductivity determinations at or near 100° could be found in the literature. For seven of the salts named in Table 2, Krannhals [Zeit. phys. Chem. 5, 250 (1890)] determined the conductivity at 99.4°. He did not, however, as a rule begin with as concentrated solutions as those represented by the corresponding salts in Table 2, and his series are frequently incomplete. As far as conductivity determinations at 0° are concerned only a few scattered determinations could be found in the literature, which would not have been adequate for the purpose in hand. Molecular weight determinations of a goodly number of the salts under consideration are to be found in the literature, but they do not cover a sufficient range of concentration for the present purpose.

ductivity measurements at the higher temperature were made at 95° instead of at 100°. The resistance cell was immersed in a large paraffine bath whose temperature was carefully regulated at 95°.

The freezing-point determinations were made with a regular Beckmann's apparatus of large size, about 40 grams of water being used in each case. The solutions were cooled only from two to three-tenths of a degree below their freezing-points, and the crystallization was each time inaugurated by means of a point of ice. The boiling-point determinations were made with a Beckmann's apparatus of about double the ordinary size. Unless otherwise stated, appropriate Beckmann's thermometers graduated to 0.01° (made by F. O. R. Goetze in Leipzig) were used. It was at first thought best to surround the thermometer with a platinum cylinder in the boiling tube, as recommended by Jones, but it was soon found that this at times causes slight fluctuations in the boiling-point, apparently due to the fact that the solution within the cylinder is apt to be slightly more concentrated than that without.

The water used in the experiments was distilled water condensed in a block tin condenser. By drawing air freed from carbon dioxide through it for a long time its conductivity was reduced to 2×10^{-6} (or somewhat less) at room temperature. The conductvity of the water has been deducted in each case, after having been determined at the proper temperature. The substances used were all of the C. P. variety of standard makes, generally either Kahlbaum's or Schuchardt's. They were tested as to their purity and as a rule were recrystallized. When the salt contained water of crystallization, the amount of this was ascertained, and the salt was weighed in the crystallized form for the molecular weight determinations, the crystal water being added to the solvent in making the computations, so that the latter are all based on the amount of anhydrous salt in the solutions. For the conductivity determinations the appropriate quantities of salt (also calculated on the basis of the anhydrous substance) of course simply had to be made up to the required volume at the proper temperature.

TABLE 1.

ELECTRICAL CONDUCTIVITY AT O°.
(Figures represent Λ_v in reciprocal ohms.)

v.	NaCl	KCl	KI	$BaCl_2$	$KClO_3$	$NaNO_3$	KNO_3	$AgNO_3$	$Ba(NO_3)_2$	$Sr(NO_3)_2$	K_2SO_4	$MgSO_4$	$ZnSO_4$	$MnSO_4$	$CdSO_4$	$NiSO_4$	$CoSO_4$	$FeSO_4$	$CuSO_4$
¼	31.0	......	......	....	....	24.5	....	27.2	....	....	....	7.0	7.1	....	6.7	....	....	....	....
⅛	41.8	63.9	69.3	38.7	....	34.7	....	35.3	....	23.5	....	13.0	12.6	12.1	11.4	13.1	....	12.1	12.3
1	47.4	65.6	69.5	44.0	....	46.5	52.1	44.5	....	32.1	....	17.6	16.3	15.8	15.0	17.8	15.5	16.3	15.9
2	50.8	67.3	69.7	47.0	....	48.0	56.5	48.3	....	38.4	48.4	21.2	21.7	19.2	18.3	21.6	18.7	19.6	19.0
4	53.3	69.0	69.9	50.6	55.4	49.0	60.6	53.3	41.9	43.2	52.6	25.2	24.7	23.4	21.3	25.3	22.0	23.0	22.4
8	55.7	70.6	71.5	53.8	60.2	52.8	63.8	57.8	45.6	47.8	56.7	29.5	28.3	26.1	25.0	28.9	25.7	28.1	26.2
16	57.9	73.0	73.5	57.0	63.2	55.7	66.6	60.1	50.4	51.3	61.8	33.7	32.2	31.2	29.5	33.9	30.2	31.4	31.0
32	59.5	75.0	76.5	60.0	65.6	57.6	70.2	63.7	55.2	55.5	65.2	38.7	37.0	35.8	34.3	39.0	34.7	36.3	35.9
64	60.9	76.6	77.7	63.8	67.7	59.7	72.7	66.6	59.3	58.4	68.8	43.3	41.9	41.0	40.3	44.8	40.0	41.7	41.2
128	62.3	77.7	78.9	68.9	69.0	61.1	73.9	67.8	62.6	61.0	71.5	47.9	47.5	46.3	45.6	50.8	45.6	47.2	46.8
256	64.2	78.9	79.4	71.0	70.3	62.3	75.5	68.8	64.9	63.1	74.8	52.7	52.9	51.4	50.8	56.0	50.6	52.1	51.9
512	65.3	79.6	79.8	72.3	71.5	63.5	75.9	69.7	66.7	64.5	75.6	56.6	56.8	56.3	56.2	59.6	55.2	56.0	56.3
1024	67.7	80.5	80.7	....	72.1	64.3	76.8	70.2	67.9	66.1	76.9	60.5	61.0	59.4	59.4	63.0	58.4	59.5	60.7
2048	67.8	80.9	......	....	72.5	65.2	77.7	70.7	68.0	67.9	78.0	63.6	64.4	62.8	62.4	64.6	61.7	62.0	63.2
4096	67.7	......	......	....	....	....	78.4	70.5	....	68.0	79.0	66.2	65.4	65.6	63.4	65.9	64.3	63.4	66.4
8192	......	......	......	....	....	....	....	....	....	....	....	67.8	65.9	65.5	....	....	64.7	64.9	67.3

TABLE 2.

ELECTRICAL CONDUCTIVITY AT 95°.

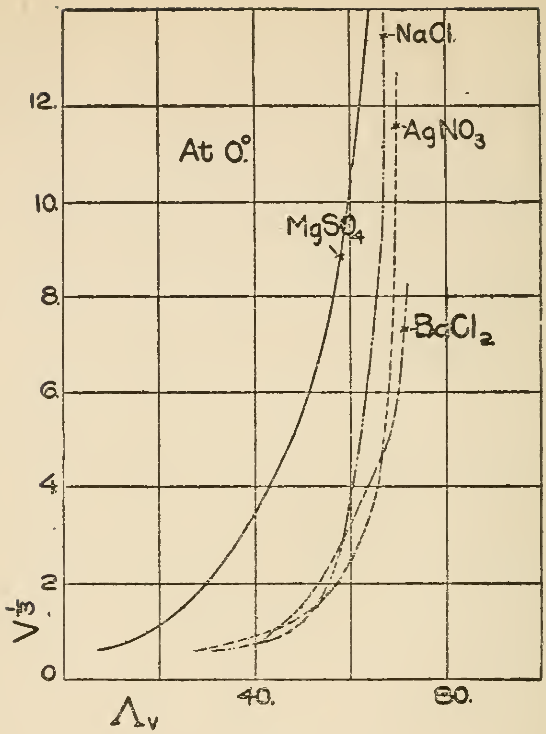
(Figures represent Λ_v in reciprocal ohms.)

V	NaCl	KCl	KBr.	KI	$MgCl_2$	$BaCl_2$	$HgCl_2$	$KClO_3$	KNO_3	$AgNO_3$	$MgSO_4$	$ZnSO_4$	$MnSO_4$	$CdSO_4$	$NiSO_4$	$CoSO_4$	$FeSO_4$	$CuSO_4$
¼	115.9	169.1	121.9	114.3	....	....	....	....	....	....	....	....	....	....	....	....	....	....
½	156.1	213.2	222.8	216.3	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1	206.7	261.0	245.4	252.8	158.7	146.3	....	185.9	198.1	180.5	75.6	64.2	58.2	52.5	70.8	64.8	60.6	58.8
2	218.5	271.9	265.3	261.7	183.4	171.1	1.93	208.3	216.6	205.0	91.1	76.7	70.0	63.6	84.5	74.7	74.3	67.9
4	236.3	284.8	286.0	274.3	197.5	193.9	2.12	235.6	251.3	228.7	103.7	87.8	84.7	74.6	98.7	87.8	89.2	76.8
8	267.5	289.5	296.4	296.3	222.6	218.5	3.98	248.7	269.4	214.4	121.0	101.0	100.4	88.6	114.2	107.8	103 5	92.2
16	271.5	313.2	317.7	305.4	235.1	240.4	5.24	266.2	288.2	252.4	142.7	123.2	119.6	109.7	133.4	123.9	125.5	108.7
32	277.2	334 4	325.8	315.1	257.7	276.1	8.78	284.1	304.6	286.8	169.7	149.4	141.4	131.2	157.2	144.7	141.2	133.8
64	288.9	360.3	338.1	331.6	272.1	297.1	14.40	300.0	320.4	293.7	194 7	172.0	171.2	152.2	183.2	178.0	173.0	150.5
128	302 6	363.9	340.4	341.4	278.6	308.1	18.60	310.3	323.1	303.0	227.4	202.9	197.3	185.6	213.0	209.6	211.5	180.8
256	310.0	373.5	343.9	348.2	285.2	326.0	28.77	320.8	330.1	309.0	259.6	232.1	236.4	225.1	253.4	241.0	250.3	218.9
512	318.8	401.8	351.5	357.5	290.9	338.9	45 90	327.7	338.7	319.3	295.4	257.4	275.4	261.7	298.6	282.7	275.9	246.8
1024	328.3	419.8	360.5	368.2	319.3	352.8	77.07	333.6	349.9	322.3	335.4	263.4	309 8	300.2	316.8	321.2	319.9	275.9
2048	339.1	433.3	375.0	389.8	317.1	363.1	106.2	337.9	349.6	343.4	387.6	277.6	338.6	357.0	359.6	383.4	413.1	298.3

In Table 1 are given the results of the conductivity measurements at 0°, while in Table 2 the values obtained at 95° are presented. The numbers in each case indicate the equivalent conductivity (Λ_v) in reciprocal ohms. The value of v indicates the volume in liters in which a gram-equivalent is contained.

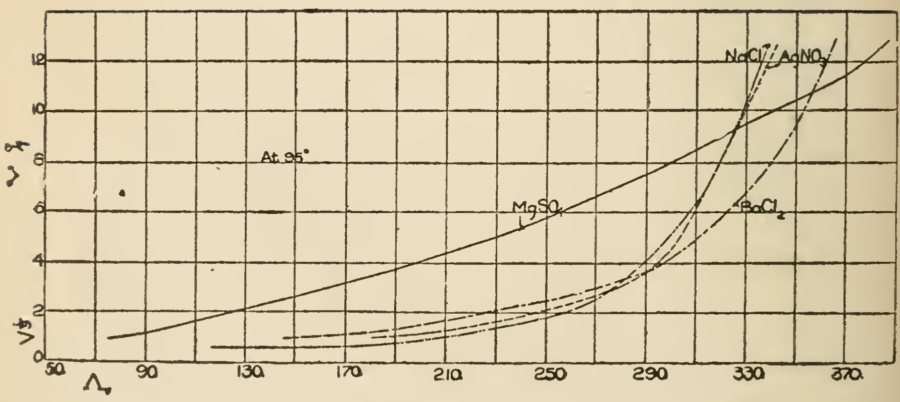
An inspection of Tables 1 and 2 shows that in each case Λ increases with the dilution, which fact has also been observed by other investigators[1] who have determined the conductivity of these salts at 18° and 25°. The general manner in which the equivalent conductivity increases with the dilution can best be seen by charting the results in the form of curves. For the salts here under consideration, it is true in general that Λ increases with increase of v in a similar manner in the cases of salts that are chemically analogous. Thus if curves be charted in which ordinates represent the volumes and abscissas the conductivities, these curves will have a similar trend in the case of the chlorides, the same will be true for the nitrates as a group, and again for the sulphates as a group. At the same time the curves for the nitrates are very similar to those of the chlorides, but the sulphates have curves with more of a characteristic trend of their own. It was deemed unnecessary to present here the curves for all the salts in Tables 1 and 2. While they have all been plotted, it will suffice for the present purpose to reproduce curves of the various types of salts contained in the tables. As such typical salts $NaCl$, $BaCl_2$, $MgSO_4$ and $AgNO_3$ have been selected. Figures 1 and 2 show the trend of the curves at 0° and at 95° respectively, the ordinates representing the cube roots of the volumes and the abscissas the equivalent conductivities. The shape of the curves of KCl and KI is similar to that of $NaCl$; the shape of the curves of $ZnSO_4$, $MnSO_4$, $CdSO_4$, $NiSO_4$, $CoSO_4$, $FeSO_4$, and $CuSO_4$ closely resembles that of $MgSO_4$; while KNO_3 and $NaNO_3$ have curves much like that of $AgNO_3$. The great similarity between the curves of the chlorides and those of the nitrates has already been alluded to. This similarity is clearly shown by the curves rep-

[1] Compare for instance the tables in Kohlrausch und Holborn,—Das Leitvermögen der Elektrolyte.



At 0°
NaCl
AgNO$_3$
MgSO$_4$
BaCl$_2$
12.
10.
8.
6.
4
2
0
$V^{-\frac{1}{3}}$
40.
80.
Λ_v

FIG. 1.



At 95°
NaCl
AgNO$_3$
MgSO$_4$
BaCl$_2$
12
10
8
6
4
2
0
$V^{\frac{1}{3}}$
50
90
130
170
210
250
290
330
370
Λ_v

FIG. 2.

resented in the figures. A comparison of Figs. 1 and 2 shows that at 95° the $MgSO_4$ curve is practically a straight line, and that the curves of NaCl, $BaCl_2$, and $AgNO_3$ also exhibit a marked tendency to straighten out at the higher temperature. It should be stated in this connection that the curve for $CdSO_4$[1] preserves more of its convexity toward the axis of abscissas at 95° than do the curves for the other sulphates. Curves that were charted from data obtained for the same salts at 18° and at 25° showed a marked similarity[2] to those in Fig. 1 (at 0°) and indicate that the change in the shape of the curves at 0° and at 95° takes place gradually as the temperature rises. It should be clearly borne in mind that the curves for even very closely analogous salts are not perfectly parallel; all that can be said of them is that they are similar in trend.

The results of the freezing-point determinations are given in Tables 3 to 11. The headings of the tables are self-explanatory. In calculating the molecular weights 18°.9 was assumed as the lowering of the freezing-point caused by the presence of one gram-molecule in 100 grams of water.

TABLE 3.[3]

Sodium Chloride (NaCl) Mol. Wt. 58.5.

Am't NaCl in 100 g. Water.[4]	Lowering of the Freezing-point.	Molecular Weight.
1.1956	0.693	32.6*
2.5509	1.512	31.9
2.9707	1.750	32.1*
3.9273	2.300	32.3*
4.9146	2.866	32.4
5.7419	3.395	31.7*

[1] This curve is not represented in the figures. The curve for $HgCl_2$—also not represented—is practically a straight line at 95°.

[2] Such similarity has also been pointed out at various times by other observers.

[3] The four determinations marked * in this table were made in this laboratory by Mr. G. M. Wilcox. The other two determinations were made by the writer.

[4] In this table, and also in the succeeding tables (4 to 31), the computation of the amount of solute contained in 100 grams of water has been carried out to more decimal places than is necessary. Through an inadvertence these numbers were not rounded off to fewer decimal places, as they should have been, especially in the case of the more concentrated solutions.

TABLE 4.

Magnesium Sulphate ($MgSO_4$) Mol. Wt. 120.4.

Am't $MgSO_4$ in 100 g. Water.	Lowering of the Freezing-point.	Molecular Weight.
0.6994	0.154	85.8
1.5173	0.314	91.3
2.5506	0.480	100.4
5.9948	1.006	112.6
6.9618	1.165	112.9
9.2469	1.527	114.5

TABLE 5.

Zinc Sulphate ($ZnSO_4$) Mol. Wt. 161.5.

Am't $ZnSO_4$ in 100 g. Water.	Lowering of the Freezing-point.	Molecular Weight.
1.6029	0.258	117.4
5.0266	0.625	152.0
8.9621	1.030	164.5
10.9305	1.246	165.8
13.6750	1.493	173.1
16.9351	1.922	166.5

TABLE 6.

Manganous Sulphate ($MnSO_4$) Mol. Wt. 151.1.

Am't $MnSO_4$ in 100 g. Water.	Lowering of the Freezing-point.	Molecular Weight.
1.9410	0.293	125.2
2.5022	0.361	131.0
5.1208	0.687	140.9
10.8430	1.399	146.5
18.5720	2.591	135.5

TABLE 7.

Cadmium Sulphate ($CdSO_4$) Mol. Wt. 208.1.

Am't $CdSO_4$ in 100 g. Water.	Lowering of the Freezing-point.	Molecular Weight.
3.0714	0.313	185.5
8.6084	0.742	219.3
15.6400	1.322	223.6
22.6470	1.968	217.5
26.1200	2.330	211.9

TABLE 8.

Nickelous Sulphate ($NiSO_4$) Mol. Wt. 154.8.

Am't $NiSO_4$ in 100 g. Water.	Lowering of the Freezing-point.	Molecular Weight.
1.0777	0.189	107.8
2.3642	0.351	127.3
4.3320	0.557	147.0
5.8966	0.779	143.1
10.4433	1.284	153.7
16.0307	1.984	152.7

TABLE 9.

Colbaltous Sulphate ($CoSO_4$) Mol. Wt. 155.1.

Am't $CoSO_4$ in 100 g. Water.	Lowering of the Freezing-point.	Molecular Weight.
1.4570	0.209	131.8
2.9824	0.390	144.5
4.9278	0.600	155.2
9.6574	1.067	171.2
14.1430	1.587	168.5

TABLE 10.

Ferrous Sulphate ($FeSO_4$) Mol. Wt. 152.1.

Am't $FeSO_4$ in 100 g. Water.	Lowering of the Freezing-point.	Molecular Weight.
2.2709	0.316	135.8
2.6514	0.376	133.3
6.5028	0.794	154.8
8.9803	1.072	158.4
13.8490	1.655	158.2

TABLE 11.

Copper Sulphate ($CuSO_4$) Mol. Wt. 159.7.

Am't $CuSO_4$ in 100 g. Water.	Lowering of the Freezing-point.	Molecular Weight.
1.8354	0.300	115.6
3.3127	0.405	154.6
6.4435	0.743	163.9
9.2425	0.996	175.4
14.2100	1.569	171.2

Tables 3 to 11 do not contain all the salts represented in Table 1. The freezing-points of barium chloride solutions have lately been determined by Jones and Chambers[1] between approximately the concentrations 0.1 and 0.6 normal, as have also those of chlorides and bromides of other alkaline earths. Table 3, giving the results obtained with NaCl, indicates that for the concentrations investigated (0.2 to 1.0 normal approximately) the molecular weight is practically constant. For about 0.2 normal the molecular weight was found to be 32.6, which corresponds to a dissociation of 79.4 per cent.; for an approximately normal solution the molecular weight was found to be 31.7, which corresponds to a dissociation of 84 per cent. These two results represent the extreme variations of the values in Table 3. For the average value of the six determinations, 32.2, the dissociation is 81 per cent. According to Table 1 the degree of dissociation (calculated according to the usual formula $\frac{\Lambda_v}{\Lambda_\infty}$) is about 79 per cent. for the 0.2 normal solution and 70 per cent. for the normal solution.[2] The degrees of dissociation 79 per cent. and 70 per cent. correspond respectively to the molecular weights 32.7 and 34.4. It is clear then, that the degree of dissociation for the most dilute solution tested is found to be the same by freezing-point and conductivity methods to within the experimental error of the former method. But the dissociation increases rapidly with the dilution according to the conductivity, whereas the freezing-point results show that it at least remains constant, if it does not diminish with the increase of the dilution within the limits tested. C. Dieterici[3] has shown by his very careful measurements of the diminution of the vapor tension of NaCl solutions at 0° that between the limits 0.1 and 1.0 normal the molecular diminution of the vapor tension decreases as the dilution increases. R. W. Wood[4]

[1] Amer. Chem. Jour. 23, 89 (1900).

[2] In calculating the degrees of dissociation from the conductivity the values of the conductivity at infinite dilution were taken either directly from the highest values given in the table of conductivites; or when the trend of the curve (which was in all cases charted) required it, from the careful extrapolation of the curve.

[3] Wied. Ann. 62, 616 (1897).

[4] Zeit. phys. Chem. 18, 522 (1895).

found that the degree of dissociation of KCl, while nearly the same by cryoscopic and conductivity methods at a concentration slightly above 0.1 normal, increases more rapidly with the dilution by the latter than by the former method.

In the case of $MgSO_4$ (Table 4) the solutions examined varied in concentration from about 0.1 to 1.5 normal. The degree of dissociation for the most dilute solution being 40 per cent. and for the most concentrated only 5 per cent. According to the conductivity determinations (Table 1) the corresponding degrees of dissociation are 44 and 22 per cent. respectively. The discrepancy between the dissociation as determined by the two methods, then, while relatively rather small at first, increases enormously with the concentration within the limits investigated.

Zinc sulphate (Table 5) shows no dissociation according to the freezing-point determinations when the solutions contain a gram-equivalent or more of the salt per liter, and yet zinc sulphate solutions have an electrical conductivity nearly the same as that of the equivalent solutions of $MgSO_4$ (Table 1). The most dilute solution represented in Table 5 yielded a molecular weight of 117.4, corresponding to a dissociation of 38 per cent.; the conductivity method yields about 40 per cent. For the normal solution, where the dissociation is nil according to the cryoscopic work, it is 24 per cent. according to the conductivity.

Manganous sulphate (Table 6) at first shows an increase of molecular weight with the increase of concentration and then a decrease. This also appears in the case of $ZnSO_4$ (Table 5) though less markedly. Again $CdSO_4$ (Table 7) shows this behavior in a marked degree, while $NiSO_4$ (Table 8), $CoSO_4$ (Table 9) and $CuSO_4$ (Table 11) show it slightly, and possibly also $FeSO_4$ (Table 10). The electrical conductivity of $MnSO_4$ solutions increases regularly with the dilution, as does that of solutions of all the other sulphates investigated. It is clear that according to the conductivity determinations the dissociation constantly increases with the dilution in the case of

the particular sulphates just enumerated, whereas according to the cryoscopic determinations, there is at first a decrease of dissociation with increase of concentration, and then an increase of dissociation with increase of concentration. The most dilute solution of $MnSO_4$ tested (about 0.25 normal) gave a molecular weight of 125.2, corresponding to 2 per cent. dissociation, whereas the conductivity method yields about 35 per cent. When the molecular weight is 146.5 the dissociation is 3 per cent., the conductivity indicates 20 per cent.

It is practically useless to make the comparison in the case of $CdSO_4$ (Table 7) for the cryoscopic determinations show no dissociation except in the most dilute solution tested; whereas, as stated above, the conductivity of the solutions is excellent and increases regularly with the dilution. The most dilute solution, in which a molecular weight of 185.5 was found would contain the salt dissociated to the extent of 12 per cent.; the conductivity results yield about 30 per cent.

Nickel sulphate is practically undissociated according to cryoscopic determinations (Table 8) when the solution is about ten per cent. strong. The conductivity at about this strength indicates 22 per cent. dissociation. The molecular weight of the most dilute solution investigated corresponds to 43 per cent. dissociation; the conductivity indicates 42 per cent.

In the case of $CoSO_4$ the freezing-point indicates no dissociation in a solution about 5 per cent. strong or stronger (Table 9), whereas the conductivity determinations show about 26 per cent. dissociation when the observed molecular weight is 155.2. In the most dilute solution the molecular weight found is 131.8 corresponding to 18 per cent. dissociation; the conductivity indicates about 34 per cent.

According to cryoscopic determinations $FeSO_4$ also is undissociated in about six per cent. solutions or over (Table 10). When the observed molecular weight is 154.8 the conductivity nevertheless indicates 24 per cent. dissociation. The most dilute solution shows a molecular weight of 135.8 or 12 per cent. dissociation; the conductivity indicates 30 per cent.

Copper sulphate is also undissociated in 5 per cent. solutions or over (Table 11). When the molecular weight observed equals 163.9, which corresponds to no dissociation, the conductivity indicates about 22 per cent. dissociation. In the most dilute solution tested, the molecular weight found, 115.6, corresponds to 38 per cent. dissociation; the conductivity indicates about 32 per cent.

From the foregoing it is evident that with the exception of a few instances (and these at certain special concentrations) the agreement between the value of the degree of dissociation, as calculated from the freezing-point of the solutions, and that deduced from their conductivity, must in general be pronounced poor, even in the case of the most dilute solutions tested; while in the somewhat stronger solutions there is no agreement at all, many of the cryoscopic determinations showing no dissociation, whereas the conductivity indicates quite appreciable dissociation.

Arrhenius[1] in his original table presents figures from cryoscopic data indicating no dissociation for $MgSO_4$, $FeSO_4$, $CuSO_4$, $ZnSO_4$, and $CdSO_4$, whereas the electrical conductivity (he used the results obtained at room temperatures) showed considerable dissociation, which agrees substantially with the results above recorded for the stronger solutions. Cadmium iodide, as Arrhenius shows, exhibits a similar behavior. Arrhenius seeks to explain away the discrepancy in the case of the sulphates mentioned by assuming that the inactive or undissociated molecules in the solutions are polymerized; and he seeks to base this assumption on the fact that Hittorf[2] found the migration numbers of $MgSO_4$ and $ZnSO_4$ to show a considerable variation with the concentration, which was also found to be true—though much more markedly—in the case of CdI_2, for which Hittorf assumed double molecules in the solution in order to explain the phenomena he observed. The latter also clearly states that he applies the same explanation to the other salts of the magnesia series, for their migration

[1] l. c.

[2] Pogg. Ann. 106, 547 (1859).

numbers also vary considerably with the concentration. This at first seems to justify perfectly the position taken by Arrhenius. However, the latter has not applied the explanation to all the salts of the magnesia series, as he ought to, but he has simply assumed polymerized molecules in the case of those salts that did not behave according to his theory. He ought to assume polymerized molecules in the case of $MgCl_2$, for instance, for Hittorf found the migration numbers of this salt strongly dependent upon the concentration, as he did those of $MgSO_4$. But it happens that to assume polymerized molecules in the case of $MgCl_2$ would be very inconvenient for Arrhenius' theory, as his calculations of the factor i show, and so he did not make the assumption which he, in order to be consistent, ought to have made. In the case of $CaCl_2$, $BaCl_2$, $Ca(NO_3)_2$, $Ba(NO_3)_2$, Hittorf likewise found the migration numbers strongly dependent upon the concentration, yet Arrhenius does not assume polymerized molecules for these, as he ought to, to be consistent, for these salts agree better with his theory when such an assumption is not made. To assume polymerization of the molecules of such salts as $MgCl_2$, $CaCl_2$ and $BaCl_2$ would lead to the greatest difficulty also in harmonizing the freezing-point results obtained by Jones and Chambers[1] with the dissociation theory; for they have found that the molecular lowering shows a minimum between the strengths 0.1 and 0.2 normal, and that in concentrated solutions the lowering is as great or greater than the theoretical lowering, if the compounds were completely electrolytically dissociated. Jones and Chambers seek to harmonize their "abnormal" freezing-point lowerings by assuming that the salts form hydrates in the solutions. There can hardly be any doubt that the salts in question unite with water to form hydrates; but when the authors seek to use this to explain the "abnormally" low freezing-points of solutions, it might be well to remind them that the dissociation theory itself was promulgated to explain "abnormally" low freezing-points of solutions, and that since they have found the theory

[1] Amer. Chem. Jour. 23, 89 (1900). Compare also in this connection Chambers and Frazer, Ibid. 23, 512 (1900).

unable to do this and have reached out to the hydrate theory for help, it might be well in the face of the facts to acknowledge freely the weakness of the dissociation theory and to proceed to explain the facts on the basis of the hydrate theory alone. If it be urged that the solutions conduct electricity and therefore the salts must be electrolytically dissociated,—the answer is, they must be, only if the dissociation theory be assumed.

Attention must now be directed especially to the careful determinations of C. Dieterici[1], who measured the lowerings of the vapor tensions of a series of aqueous solutions of electrolytes and non-electrolytes at 0°. He found that for $CaCl_2$ the molecular lowering of the vapor tension diminishes strongly with increase of the dilution, and then at about 0.1 normal it again increases with the dilution. He also emphasizes the fact that the very careful freezing-point work of Loomis[2] and of Ponsot[3] shows a minimum of the molecular lowering of the freezing-point at nearly the same concentration. The work of Jones and Chambers above cited also corroborates this. Between the concentrations 0.1 and 1.0 normal, to which Dieterici's work is really limited, he found that for the substances tested (H_3PO_4, H_2SO_4, NaCl, $CaCl_2$, cane sugar, dextrose and urea) the molecular lowering of the vapor tension diminishes as the dilution increases, which is the opposite of that which the theory of Arrhenius requires. In view of this fact Dieterici rightfully refrains from even attempting to make a further comparison between the degree of dissociation as calculated from the vapor tension measurements on the one hand and the conductivity on the other. The reader is also referred to the able critical consideration of the very careful freezing-point determinations of various investigators which is contained in Dieterici's article.

Attention is now called to the results of the boiling-point determinations (Tables 12 to 29). For a number of the most important salts represented in these tables, two, and in a few

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[1] l. c.
[2] Wied. Ann. 51, 500 (1894); Ibid. 57, 495 (1896); Ibid. 60, 523 (1897).
[3] Recherches sur les congélations, Gauthiers and Villars, Paris (1896).

instances three or four, series of determinations were made by Mr. Koch, in order to be perfectly sure of the facts.

TABLE 12.

Sodium Chloride (NaCl) Mol. Wt. 58.5.

Am't NaCl in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
	(Series 1.)		
1.1395	0.197	747.7 mm.	33.4
4.1674	0.744	747.1	32.4
5.5246	1.002	747.0	31.9
8.2543	1.553	747.0	30.0
11.0105	2.157	746.9	29.5
15.9109	3.304	746.9	27.8
20.5207	4.495	746.8	26.4
	(Series 2.)		
2.9004	0.499	743.6 mm.	33.6
6.0065	1.082	743.5	32.1
7.1036	1.690	743.5	30.6
12.6259	2.514	743.5	29.0
15.6403	3.231	743.5	28.0
18.5305	4.032	743.5	26.7
20.1309	4.471	743.5	26.0
	(Series 3.)[1]		
1.256	0.195	754	33.5
2.500	0.390	754	33.3
3.739	0.598	754	32.5
5.046	0.820	754	32.0
6.299	1.031	754	31.8
8.792	1.474	754	31.0
11.409	1.970	754	30.1
	(Series 4.)		
10.090	1.68	743.7 mm.	31.5
12.902	2.23	743.7	30.4
15.631	2.77	743.7	29.6
19.043	3.70	743.4	27.0
22.950	4.56	743.4	25.8
25.320	5.28	743.4	25.2
28.697	6.17	743.4	24.4
31.242	6.82	743.4	24.1

[1]The results in Series 3 are those of Mr. G. M. Wilcox. In Series 4 a thermometer graduated to tenths, which readily permitted the hundredths to be estimated with the aid of a lens, was used, the temperature range being greater than that of the Beckmann's thermometer.

TABLE 13.[1]

Potassium Chloride (KCl) Mol. Wt. 74.59.

Am't KCl in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
	(Series 1.)		
2.1223	0.293	737.6 mm.	41.9
5.1243	0.700	737.6	42.3
9.0126	1.247	737.6	41.8
13.9904	2.004	737.6	40.4
20.1703	2.975	737.6	39.2
24.1601	3.653	737.6	38.2
27.7204	4.266	737.6	37.7
31.8402	5.009	737.6	36.8
	(Series 2.)		
1.9117	0.255	744.0 mm.	43.3
4.0524	0.554	744.0	42.3
7.2257	0.986	744.0	42.4
11.6205	1.625	743.9	41.3
16.5203	2.406	744.0	39.4
21.3504	3.206	744.0	39.5
26.1305	3.911	744.2	38.5
30.3701	4.756	744.1	37.1
	(Series 3.)		
5.676	0.65	736.1 mm.	45.4
7.427	0.91	736.1	42.4
10.001	1.25	736.1	41.6
12.447	1.59	736.2	40.7
15.949	2.05	736.2	40.5
19.676	2.60	736.2	39.6
23.937	3.18	736.2	39.1
27.174	3.75	736.3	37.7
30.868	4.30	736.3	37.3
34.901	5.00	736.3	36.2
38.491	5.60	736.2	35.7
42.268	6.28	736.2	35.0
45.862	6.88	736.2	34.7
48.935	7.60	736.2	34.2

[1] In Series 3 the thermometer graduated to tenths was used.

TABLE 14.

Potassium Bromide (KBr) Mol. Wt. 119.1.

(Series 1.)

Am't KBr in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
2.6145	0.206	740.2 mm.	66.1
5.5045	0.433	740.2	66.1
9.5939	0.763	740.2	65.4
16.5033	1.351	740.2	63.7
23.3933	1.968	740.2	61.8
28.1778	2.413	740.2	60.7
33.2787	2.899	740.2	59.7
38.4978	3.425	740.2	58.4
43.4181	3.932	740.2	57.4
47.0656	4.312	740.2	56.8
51.2044	4.778	740.2	55.7

(Series 2.)

3.3803	0.244	739.5 mm.	72.0
5.6569	0.449	739.5	65.5
9.4227	0.725	739.5	67.6
13.4884	1.066	739.5	65.8
17.9788	1.437	739.5	65.0
22.3104	1.854	739.5	62.6
26.4854	2.249	739.5	61.2
30.4400	2.677	739.5	59.1
34.7605	3.115	739.5	58.0
39.7854	3.656	739.5	56.6
45.3672	4.267	739.5	55.3
49.0660	4.735	739.5	53.9

TABLE 15.

Potassium Iodide (KI) Mol. Wt. 166.

(Series 1.)

Am't KI in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
2.8034	0.155	736.1 mm.	94.0
7.0320	0.397	736.1	92.1
10.8010	0.620	736.1	90.6
14.9234	0.870	736.1	89.2
19.7824	1.184	736.1	86.9
24.5374	1.494	736.0	85.4
29.2440	1.812	736.0	83.9
33.6664	2.134	736.0	82.0
39.0590	2.511	736.0	80.9
47.6110	3.159	736.0	78.4

(Series 2.[1])

4.1747	0.23	740.6 mm.	94.3
6.1779	0.33	740.4	97.3
12.9296	0.72	740.4	93.3
19.0241	1.10	740.4	89.8
26.2379	1.58	740.0	86.4
35.0032	2.14	740.0	85.0
43.0591	2.74	739.4	81.6
66.2534	4.67	739.4	73.4
77.1725	5.55	739.5	72.1
85.7187	6.36	739.5	70.0
92.7357	7.02	739.5	68.6
104.8054	8.02	739.5	67.9

[1]The thermometer graduated to tenths was used in this series.

TABLE 16.

Magnesium Chloride ($MgCl_2$) Mol. Wt. 95.26.

Am't $MgCl_2$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
3.3713	0.416	750.1 mm.	42.1
6.1999	0.850	750.0	37.9
9.1560	1.351	749.0	35.2
13.8696	2.380	750.0	30.3
16.8024	3.164	749.8	27.6
20.4226	4.243	749.8	25.0
22.0560	4.720	749.6	24.3

TABLE 17.

Barium Chloride ($BaCl_2$) Mol. Wt. 208.3.

(Series 1.)

Am't $BaCl_2$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
4.0785	0.242	742.8 mm.	89.7
8.7778	0.525	742.8	86.9
13.4221	0.825	742.8	84.7
18.6191	1.174	742.9	82.5
22.0768	1.586	742.9	78.9
32.0760	2.243	742.9	74.2
40.4680	2.970	742.9	70.9
47.8792	3.625	742.9	68.7
54.5198	4.157	742.9	68.2

(Series 2.)

Am't $BaCl_2$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
3.3971	0.208	752.8 mm.	84.9
8.2907	0.496	752.8	86.6
13.6126	0.839	752.8	84.4
19.8682	1.293	725.8	79.9
27.0710	1.909	752.8	75.5
35.0366	2.517	752.8	72.4
38.8437	2.877	752.8	70.2
44.2550	3.362	752.8	68.5
48.1307	3.737	752.8	67.0
53.8634	4.157	752.8	67.3

TABLE 18.

Mercuric Chloride ($HgCl_2$) Mol. Wt. 270.9.

Am't $HgCl_2$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
3.3416	0.056	751 mm.	310.1
8.5806	0.143	751	312.0
15.4630	0.248	750.9	324.2
24.8581	0.376	750.9	343.8
34.9070	0.496	750.8	366.4
45.8779	0.600	750.6	397.6
52.5994	0.645	750.5	423.1

TABLE 19.[1]

Potassium Chlorate ($KClO_3$) Mol. Wt. 122.6.

Am't $KClO_3$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
3.7431	0.34	738.8 mm.	57.2
8.1214	0.65	738.8	66.4
12.8379	1.01	738.6	66.0
17.1163	1.31	738.6	67.9
23.4841	1.72	738.4	70.9
29.6893	2.10	738.4	76.7
35.4205	2.49	738.1	73.9
42.9627	2.98	738.1	74.9
48.9283	3.43	737.6	74.1

[1] This series of determinations was made with the thermometer graduated to tenths.

TABLE 20.

Potassium Nitrate (KNO_3) Mol. Wt. 101.2.

(Series 1.)

Am't KNO_3 in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
2.7896	0.248	741.1 mm.	58.5
6.0580	0.518	741.1	60.8
9.7271	0.822	741.1	61.5
14.7986	1.207	741.1	63.8
21.3338	1.706	741.2	65.0
27.0956	2.123	741.2	66.4
33.8032	2.577	741.2	68.2
41.5423	3.079	741.2	70.2
49.4270	3.570	741.3	72.0
57.2081	4.027	741.4	73.9
62.8302	4.357	741.4	75.0

(Series 2.)

4.2864	0.378	744.5 mm.	59.1
8.4346	0.725	744.6	60.5
13.0686	1.101	744.6	61.7
19.7400	1.603	744.6	64.0
28.0569	2.212	744.6	66.0
35.5446	2.710	744.8	68.2
44.5312	3.275	744.9	70.7
53.3702	3.795	744.9	73.1
61.6405	4.309	744.9	74.4
70.7683	4.677	744.9	78.7

TABLE 21.

Silver Nitrate ($AgNO_3$) Mol. Wt. 170.0.

(Series 1.)

Am't $AgNO_3$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
3.8939	0.197	739.4 mm.	102.8
11.9266	0.570	739.4	106.3
23.3420	1.066	739.4	113.9
35.0895	1.523	739.4	119.8
45.8973	1.915	739.4	124.6
56.3032	2.249	739.4	129.9
68.6870	2.636	739.4	135.5
83.3849	3.047	739.4	142.3
99.7473	3.521	739.4	147.3
110.2273	3.755	739.4	152.6
122.3325	4.060	739.4	156.7
136.2615	4.398	739.4	161.1

(Series 2.)

8.3155	0.422	738.8 mm.	102.4
16.2894	0.772	738.7	109.7
25.1374	1.091	738.7	119.8
30.6129	1.526	738.7	131.3
45.3921	1.887	738.7	125.4
54.3253	2.178	738.7	135.9
65.4093	2.516	738.7	135.2
74.5296	2.790	738.7	138.9
86.4310	3.143	738.5	143.0
99.7190	3.496	738.4	148.3
115.2352	3.900	738.4	153.7
136.4676	4.431	738.4	160.2

TABLE 22.

Magnesium Sulphate ($MgSO_4$) Mol. Wt. 120.4.

Am't $MgSO_4$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
2.7333	0.097	739.3 mm.	146.5
7.2368	0.281	739.3	168.6
27.5802	0.524	739.3	273.7
36.9100	0.925	739.3	207.5
43.4772	1.455	739.3	155.4
52.7743	1.984	739.3	138.3
60.5241	3.220	739.3	97.7
64.3938	3.316	739.4	101.0
72.2893	3.630	739.4	105.9

TABLE 23.

Zinc Sulphate ($ZnSO_4$) Mol. Wt. 161.5.

Am't $ZnSO_4$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
2.8860	0.080	743.0 mm.	187.6
6.6472	0.169	743.0	204.5
10.1392	0.266	743.0	198.2
13.3894	0.372	743.0	201.1
17.7137	0.461	743.0	199.8
22.2021	0.591	743.0	190.5
25.1993	0.690	743.0	189.9
28.2497	0.811	743.0	181.1
30.4712	0.890	742.0	176.3
32.8944	0.995	742.0	171.9
35.1802	1.122	742.0	163.0
37.3689	1.240	742.0	156.7
39.8343	1.381	742.0	150.0
41.3019	1.459	742.0	147.2
44.5661	1.671	742.0	138.7

TABLE 24.

Manganous Sulphate ($MnSO_4$) Mol. Wt. 151.1.

Am't $MnSO_4$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
3.7134	0.114	739 mm.	169.4
7.1327	0.193	739	192.2
10.2505	0.282	739	194.1
14.4644	0.373	739	201.7
19.3494	0.520	739	193.5
24.2095	0.678	739	185.7

TABLE 25.

Cadmium Sulphate ($CdSO_4$) Mol. Wt. 208.1.

Am't $CdSO_4$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
4.5635	0.105	741.3 mm.	225.8
10.9721	0.215	741.3	265.4
15.0901	0.287	741.3	273.5
20.6623	0.356	741.3	301.7
24.7605	0.385	741.3	334.4
27.7718	0.494	741.3	292.3
32.9341	0.604	741.3	283.5
36.7641	0.699	741.3	273.4
41.2807	0.820	741.3	261.8
47.3809	0.988	741.3	249.3
53.4751	1.164	741.3	239.4

TABLE 26.

Nickelous Sulphate ($NiSO_4$) Mol. Wt. 154.8.

Am't $NiSO_4$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
2.7661	0.096	737 mm.	149.8
5.2551	0.169	737	161.7
7.6761	0.230	737	173.5
11.1964	0.336	737	173.3
15.1358	0.448	737	175.7
17.9435	0.536	737	174.1
20.8475	0.641	737	169.1
23.1431	0.738	737	163.1
25.5253	0.841	737	157.8
27.1590	0.939	737	150.4
29.0219	1.042	737	144.8
31.1444	1.190	737	136.1
32.7051	1.302	737	130.6
34.4614	1.489	737	120.0
35.1654	1.576	737	118.7
37.7353	1.734	737	113.2

TABLE 27.

Cobaltous Sulphate ($CoSO_4$) Mol. Wt. 155.1.

Am't $CoSO_4$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
2.1070	0.068	736 mm.	160.8
4.4465	0.110	736	205.3
8.7442	0.201	736	226.1
9.5963	0.262	736	190.5
12.9365	0.346	736	194.3
16.1345	0.449	736	186.3
20.6000	0.568	736	188.6
22.1513	0.626	736	184.0
24.0703	0.694	736	180.8
26.1501	0.772	736	175.7
28.7453	0.876	736	170.8
32.8415	1.055	736	161.9

TABLE 28.

Ferrous Sulphate ($FeSO_4$) Mol. Wt. 152.1.

Am't $FeSO_4$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
3.2451	0.093	738 mm.	181.4
6.7048	0.182	738	191.6
9.2220	0.243	738	197.3
13.0874	0.343	738	198.4
15.8107	0.412	738	199.5
17.9628	0.483	738	193.4
22.8063	0.545	738	212.6
24.4524	0.633	738	200.9
26.6450	0.713	738	194.3
28.7886	0.805	738	185.6
30.6928	0.899	738	181.7
32.7685	0.994	738	171.4
35.3460	1.099	738	167.2

TABLE 29.

Cupric Sulphate ($CuSO_4$) Mol. Wt. 159.7.

Am't $CuSO_4$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
3.3569	0.091	742.9 mm.	191.8
7.8116	0.189	742.7	214.9
12.2085	0.186	742.7	221.5
15.9522	0.374	742.6	221.8
22.9147	0.571	742.6	208.7
27.4664	0.708	742.5	201.8
32.3565	0.874	742.5	192.5
36.4495	1.042	742.4	181.9
39.5708	1.192	742.2	172.6
44.0370	1.414	742.2	158.4
48.6314	1.692	741.9	149.5
52.0243	1.916	741.8	140.9
56.9514	2.283	741.7	129.7
64.1409	2.903	741.7	114.9
68.9859	3.363	741.7	106.7
73.7718	3.768	741.7	101.8

In table 12 giving the results for NaCl it appears that the molecular weight decreases steadily with the increase of concentration[1], becoming in the strong solutions less than half the theoretical molecular weight. The facts then indicate that the dissociation of common salt would increase with the concentration and that in solutions above about 20 per cent. the molecule would break up into more than two parts, which is impossible on the basis of the atomic theory as generally accepted. The behavior of NaCl is clearly diametrically opposed to that which we should expect according to the theory of electrolytic dissociation. The electrical conductivity of NaCl solutions increases regularly with the dilution, as table 2 shows. From the character of the boiling-point results it is clearly out of the question to make even an attempt to compare the dissociation as calculated from the molecular weight determinations with the dissociation as deduced from the electrical conductivity measurements.

What has been said concerning NaCl applies also to KCl (Table 13), KBr (Table 14) and KI (Table 15.) The molecular weights of these salts continually diminish with increase of concentration, finally becoming less than half the theoretical, whereas the conductivities increase regularly with the dilution (Table 2). It is interesting to note the similarity of the behavior of the haloid salts of the alkalies, to which attention has been previously directed in a general way.

The molecular weight of $MgCl_2$, too, decreases with the increase of the concentration (Table 16), finally becoming less than one-third the theoretical value. This salt would then have to dissociate into more than three ions, and that in concentrated solutions. On the other hand the conductivity increases with the dilution. It is again clearly useless to attempt a comparison of the degree of dissociation as computed from the observed molecular weights and the conductivity.

What has been stated concerning $MgCl_2$ applies exactly to $BaCl_2$ (Table 17), so that further comments about the behavior

[1]The same fact is also demonstrated by the determinations of Landsberger and Biltz,—Zeit. anorg. Chem. 17, 452 (1898).

of the latter salt are superfluous. It is interesting to note that these two salts of analogous composition exhibit a similar behavior, which resembles closely that of the haloid salts of the alkalies.

Mercuric Chloride (Table 18) shows no dissociation by the boiling-point method. The behavior of mercuric chloride differs from that of the salts last mentioned in that its molecular weight increases with the concentration. Of course with this behavior polymerization of the molecules with increase of concentration could consistently be assumed; it could further be assumed that some of the molecules not yet polymerized are electrolytically dissociated, and thus the observed phenomena could with these assumptions be brought into harmony with existing conceptions, at least qualitatively. The electrical conductivity of the solutions of this salt (Table 2) though relatively low, increases regularly with the dilution.

The boiling-point determinations for $KClO_3$ (Table 19) were made with a thermoneter graduated to tenths, so that the measurements are relatively less accurate than those in which the Beckmann thermometer was used. The results are sufficient to indicate, however, that in the case of this salt the molecular weight increases with the concentration, which is at least qualitatively in harmony with that which the dissociaion hypothesis requires. The degree of dissociation corresponding to a molecular weight of 66 is 86 per cent., whereas for the same strength of solution the conductivity results (Table 2) indicate a dissociation of not more than 70 per cent. No special stress is laid upon this comparison, however, because the Beckmann instrument was not employed in making the determinations.

In the case of KNO_3 (Table 20) we again have an increase of molecular weight with increase of concentration, which agrees qualitatively with the requirements of the dissociation theory. For the most dilute solution tested the molecular weight is 58.5, which corresponds to 73 per cent. dissociation; from the conductivity results (Table 2) the dissociation for this concentration is about 72 per cent.,—a satisfactory agreement. For a

normal solution the molecular weight is about 61.7 corresponding to 64 per cent. dissociation; the conductivity results yield 56 per cent. Silver nitrate (Table 21) also shows an increase of molecular weight with increase of concentration, which agrees qualitatively with the dissociation theory. The most dilute solution tested yielded a molecular weight of 102.8, corresponding to a dissociation of 65 per cent.; the conductivity results yield about 67 per cent.,—an acceptable agreement. For a normal solution the molecular weight is about 110 corresponding to 54 per cent. dissociation; the conductivity determinations indicate 52 per cent.,—again a very fair agreement. It happens, then, that the behavior of potassium and silver nitrates agrees much better with the demands of the dissociation theory at the boiling-point of the solutions than at the freezing-point[1]. It will be noted that these nitrates behave alike, and that solutions of $KClO_3$ apparently exhibit a behavior similar to that of the nitrates.

The sulphates (Tables 22 to 29) again show great similarity in their general behavior. In the case of $MgSO_4$ (Table 22) the molecular weight begins with a value somewhat above the theoretical,—which indicates no dissociation; then it increases at first with the concentration and finally it decreases with increase of concentration after having passed through a maximum, the values in the strongest solutions becoming less than the theoretical. There is clearly no irregularity in the conductivity values (Table 2) to even suggest such a behavior. What has been said about $MgSO_4$ applies also to $ZnSO_4$ (Table 23), $NiSO_4$ (Table 26) and $CuSO_4$ (Table 29). The same general behavior is also exhibited by $MnSO_4$ (Table 24), $CdSO_4$ (Table 25), $CoSO_4$ (Table 27) and $FeSO_4$ (Table 28), except that the molecular weights of these salts, while first increasing, and then decreasing, with the increase of concentration, always remain above the theoretical values. As table 2 shows, there is nothing in the conductivity results to lead one to expect such a behavior. A comparison of the freezing-point results (Tables 4 to 10) with those obtained by the boiling-point method

[1] Compare for instance Arrhenius' table l. c.

(Tables 22 to 29) shows that the molecular weight of the sulphates is less by the former than by the latter method in the case of corresponding concentrations. So that if it be assumed that these sulphates are polymerized in their solutions, it follows that this polymerization is greater at the boiling-points of the solutions than at their freezing-points, which seems unlikely.

It was thought to be of interest in this connection to investigate the behavior of a non-electrolyte. Cane sugar was selected, the results obtained with which by the boiling-point method are given in table 30. The results indicate clearly that the molecular weight diminishes appreciably as the concentration increases. Strong sugar solutions, however, do not—as is well known—conduct electricity in consequence thereof. The solution was finally tested with Fehling's solution to see whether any sugar had become inverted during the process of boiling, but no invert sugar was found. On the other hand a series of boiling-point determinations of solutions of H_3BO_3 (Table 31) shows that the molecular weight remains practically constant for very considerable changes in the concentration of this substance, considering its low molecular weight. The freezing-point of solutions of H_3BO_3[1] show that the molecular weight is lower at 0° than at 100°; and its solutions at the lower temperature really ought to be somewhat better conductors of electricity (according to the dissociation hypothesis) than they are.

[1] Compare Kahlenberg und Schreiner, Zeit. phys. Chem. 20, 548 (1896).

TABLE 30.

Cane Sugar, ($C_{12}H_{22}O_{11}$) Mol. Wt. 342.

Am't $C_{12}H_{22}O_{11}$ in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
20.757	0.30	736.6 mm.	360
29.518	0.42	736.6	366
36.155	0.55	736.6	342
42.692	0.70	736.6	310
49.389	0.75	736.6	335
57.354	0.91	736.6	328
65.978	1.13	736.6	304
77.777	1.41	736.6	280
92.972	1.77	737.1	273
103.426	2.06	737.4	261
113.402	2.20	737.6	268
114.900	2.32	737.6	258
125.159	2.57	737.6	253
137.830	2.90	737.6	247
149.131	3.20	737.6	242
159.987	3.48	737.6	239
167.550	3.70	737.6	236
175.161	3.84	737.9	237
187.185	4.25	737.9	229
197.736	4.56	738.5	226
207.189	4.80	738.5	225
222.082	5.20	739.0	222
236.989	5.60	739.0	220
248.090	5.92	739.0	218
259.191	6.11	739.0	221
266.733	6.41	739.0	216
276.223	6.71	739.1	214
289.455	7.10	739.0	212

TABLE 31.[1]

Boric Acid (H_3BO_3) Mol. Wt. 62.

Am't H_3BO_3 in 100 g. Water.	Rise of the Boiling-point.	Barometric Pressure.	Molecular Weight.
3.161	0.26	743 mm.	63.2
5.264	0.42	743	65.2
8.746	0.72	743	63.0
12.040	1.01	743	62.2
14.098	1.18	743	62.1
16.600	1.41	743	61.2
19.956	1.67	743	62.1
23.896	2.00	743	62.1
26.500	2.13	742.5	64.5
29.295	2.41	742.5	63.2
33.793	2.82	742.5	62.3
36.407	3.01	742.5	62.9

Discussion.

The difficulties which the theory of electrolytic dissociation encounters in explaining the phenomena in aqueous solutions are really insurmountable. We have seen that there are solutions which are excellent electrical conductors, and yet the molecular weight determinations show a normal molecular weight of the dissolved substance. It is clear that while in some cases the molecular weight increases with the concentration, thus according at least qualitatively with the theory, in other cases the molecular weight decreases with the increase of the concentration, finally becoming less than what it ought to be even on the assumption that electrolytic dissociation is complete. Again, in other cases the molecular weight at first increases with the concentration and then it diminishes as the concentration increases. And these phenomena are observed in solutions the conductivity of which steadily increases with the increase of the dilution. I have not given any examples of aqueous solutions in which the molecular conductivity does not increase

[1] In this series, which was really only a preliminary one, the thermometer graduated to tenths was used.

regularly with the dilution; but such cases do exist. So, for instance, the molecular conductivity of aqueous solutions of the alkaline hydroxides first increases with the dilution and then decreases as the dilution increases[1].

From the facts here presented in the case of aqueous solutions and those detailed above in the case of non-aqueous solutions, it follows that there is no such connection between the freezing-points and boiling-points of solutions on the one hand and their electrical conductivity on the other, as is claimed by the theory of electrolytic dissociation of Arrhenius. In numerous cases not even a qualitative agreement exists. A careful scrutiny of Arrhenius' original table reveals the fact that while in a certain number of instances the agreement of the values of the factor *i*, as computed from cryoscopic measurements and from conductivity determinations, is acceptable, in many cases it is poor, and again in others it is entirely wanting. To be sure, Arrhenius bases this table upon measurements which he deemed might in some cases contain large errors; but later experimental work has really only served to emphasize the presence of such discrepancies. Further we have seen that investigations of non-aqueous and of aqueous solutions have in reality yielded a host of facts which even the most ardent adherents of the dissociation theory have not been able to harmonize with it. For some facts, to be sure, explanations have been offered upon the basis of auxiliary assumptions which frequently had no root in facts, having been created simply to save the dissociation theory from being pronounced untenable.

The attempt has been made to explain all of the various properties of electrolytic solutions upon the basis of the theory of electrolytic dissociation. To these efforts attention must now be directed. The various additive properties of salt solutions as mentioned by Arrhenius and as detailed by Ostwald and by Nernst in their text-books, are presented as supporting the dissociation theory. But it is clear that even if these additive properties could be explained on the basis of the disso-

[1] The determinations of Kohlrausch show this phenomenon. See also the measurements of Kahlenberg and Lincoln, Jour. Phys. Chem. 2, 87 (1898).

ciation theory, the theory could not be based on this alone, since additive properties are well known to exist in the case of true chemical compounds, where, since there are no solutions under consideration and since there is no electrical conductivity observable, the possibility of electrolytic dissociation is entirely out of the question. In the realm of physiology, where it at first seemed that the theory of electrolytic dissociation would be particularly helpful, it has after all appeared that it can not cope with the facts[1].

The heats of neutralization of acids and bases in dilute solutions have been heralded as an argument in favor of the dissociation theory; but Crompton[2] has shown that the dissociation hypothesis is not only unnecessary to explain the heats of neutralization, but that it is really inadequate, for it does not bring the behavior of electrolytes, as far as heat changes that accompany the formation of salts in aqueous solution are concerned, into line with the behavior of non-electrolytes. It is unnecessary to dwell further upon the insurmountable difficulties which the dissociation theory meets in general in the realm of thermal chemistry. These difficulties have been sufficiently

[1] In this connection the reader is referred in particular to the following articles and to the additional references that they in turn contain: L. Kahlenberg, The Taste of Acid Salts and Their Degree of Dissociation, Jour. Phys. Chem. 4, 33 (1900). T. W. Richards, The Relation Between the Taste of Acids and Their Degree of Dissociation, Ibid. 4, 207 (1900). L. Kahlenberg, The Taste of Acid Salts and Their Degree of Dissociation II, Ibid. 4, 533 (1900). J. F. Clark, Electrolytic Dissociation and Toxic Action, Ibid. 3, 263 (1899). L. Kahlenberg and R. M. Austin, Toxic Action of Acid Sodium Salts on Lupinus Albus, Ibid. 4, 553 (1900).

In reviewing the above articles for the Jour. Amer. Chem. Soc. and the Zeit. phys. Chem., Arthur A. Noyes has made the attempt to bring the facts into harmony with the dissociation theory. I will simply state here that I have no desire whatever to enter upon a discussion of these "explanations" of Mr. Noyes, the weakness of which is sufficiently apparent upon the face of them. The facts are before the reader and he can safely be left to judge for himself. I must request the reader, however, to refer to the original of the third article in the above list, or at any rate to use the review of it given in the Chemisches Centralblatt or the Jour. Chem. Soc. (London), since Noyes has omitted to mention an essential part of the very simple experiment upon which the argument is based, and has then claimed that the experiment is irrelevant. Evidently Mr. Noyes in his ardor to uphold the dissociation theory did not see the full import of the experiment in question.

[2] Jour. Chem. Soc. (London) 71, 951 (1897). See also Crompton's interesting article on Rotations of Optically Active Salts, Ibid. p. 946.

discussed by Reychler[1], whose conclusion is that, "above everything else we notice that *the hypothesis of free ions is in opposition to thermo-chemical observations*"[2].

The attempts to harmonize the theory of electrolytic dissociation with the law of mass action have signally failed in the case of the electrolytes *par excellence,* as is well known, in spite of the fact that very earnest endeavors have been made in this direction for over a decade. In the case of weak organic acids, to be sure, a tolerable agreement between the law of mass action and the dissociation theory has been found by Ostwald. The fact that the dissociation hypothesis cannot be brought into harmony with the law of mass action is one of the strongest arguments against the theory. It is really unfortunate that in discussing problems of equilibrium into which strong electrolytes enter (their solubility for instance) the adherents of the dissociation theory should go right ahead with their mathematical equations and deductions as though the theory were in full accord with the law of mass action[3].

The chemical reactiveness of electrolytes has been explained by attempting to ascribe to the ions a peculiarly strong chemical activity on account of the electrical charges that are supposed to reside upon them.[4] The fact that a goodly number of substances will not react with each other when water is not present and that they do react in aqueous solution, or at any rate when moist, has been called into requisition in this connection. While this behavior may be claimed to agree with the dissociation theory, it cannot be used as an argument to support the latter; for it is clear that many pure substances and mixtures

[1] Outlines of Physical Chemistry. (Translated by McCrae.) Whittaker and Co. (1899), page 214.

[2] The italics are Reychler's.

[3] Compare for instance the general and unqualified statements concerning the so-called solubility product contained in Ostwald's "Scientific Foundations of Analytical Chemistry," which the author applies to electrolytes, to most of which, certainly, it does not apply unqualifiedly.

[4] A recent statement of H. C. Jones illustrates the extreme views that are entertained by some regarding this matter. He concludes a review of the work done on the dissociating power of solvents (Amer. Chem. Jour. 25, 232 (1901)) with the statement, "The chemistry of atoms and molecules has thus given place to the chemistry of ions".

in which there are no grounds whatever for assuming the presence of ions, are nevertheless exceedingly reactive chemically,—take for instance, many well known explosives as a striking example. And on the other hand it is a well recognized fact that, in many cases at least, salts, acids and bases unite chemically with water and other solvents, and that any reaction which then takes place in solution is one between these new products, and that therefore such reactions might easily occur in presence of water, whereas the anhydrous substances might not react at all. It might be helpful to some to use the language of the dissociation theory and to say, for example,—the analytical test for chlorine ions is silver ions; instead of saying, —the analytical test for chlorine in the form of a soluble chloride is silver nitrate or any other soluble silver salt in which silver is the base; but that the new terminology, coupled with an attempt to apply the law of mass action to electrolytes in a way in which it certainly does not apply, forms a scientific foundation for analytical chemistry, is a position that is clearly untenable. The very fact that analytical chemistry has not received much benefit from Professor Ostwald's little book on "The Scientific Foundations of Analytical Chemistry," in the way of improving existing analytical methods and discovering new ones, speaks for itself.

In connection with the dissociation hypothesis the solvent has been considered as having a peculiar "dissociating power". Water, then, yielding such excellent conducting solutions as it does, would have a very high degree of this dissociating power. The effort has been made by Nernst and by J. J. Thomson, practically simultaneously, to ascribe this strong dissociating power of water to its high dielectric constant, which is about 80 at room temperatures. At the time when this was done, relatively few solvents had been investigated that yielded solutions having considerable conductivity, and so it was perfectly easy to show that in the case of water, formic acid, alcohol, ether and benzol, for example, the conductivity of the solutions in which these liquids are the solvents diminishes with the dielectric constant

of the solvent.[1] The idea underlying the attempt to bring this hypothetical dissociating power into correlation with the dielectric constant of the solvent, is that a high dielectric constant of the latter would make it more difficult for the electrically charged ions to neutralize their charges by reason of the electrostatic attraction existing between them. It is not claimed that high dissociating power is proportional to the specific inductive capacity of the solvent, but simply that it increases and diminishes with it, the exact mathematical relation being as yet unknown. Since the Nernst–Thomson rule has been put forth the electrical conductivity of various salts in a goodly number of solvents has been investigated.[2] While the dielectric constants of all the solvents tested were not known at the time, so that a comparison could be made in all cases, in the majority of instances where the dielectric constants were known, the Nernst–Thomson rule was indeed corroborated.[2] At the same time a few striking exceptions were present. The relatively low dielectric constant of liquid ammonia[3] and the high conductivity[4] of solutions of salts in it, speak powerfully against the Nernst–Thomson rule. It can hardly be argued that this high conductivity in liquid ammonia is due largely to the high rate with which the ions move, because the conductivity of the solutions has been examined at the boiling-point of the solvent, —38°; for liquid ammonia has a specific inductive capacity lower than that of alcohol, and yet alcoholic solutions at their boiling-point have incomparably lower electrical conductivity than that observed in liquid ammonia solutions. Another striking exception to the Nernst–Thomson rule has recently been pointed out by H. Schlundt,[5] who found the dielectric constants of butyronitrile and pyridine to be 20.3 and 12.4, respectively, and pointed out that nevertheless the solutions in the latter solvent

[1] Compare for instance Nernst's table on page 365 of the 3d edition of his book, Theoretische Chemie, F. Enke, Stuttgart (1900).
[2] Compare Kahlenberg and Lincoln, l. c., also Lincoln, l. c., and the additional articles referred to in these papers.
[3] Goodwin and Thompson, Physical Review 8, 38 (1899).
[4] Franklin and Kraus, l. c.
[5] Jour. Phys. Chem. 5, 157 (1901).

are known to be the better conductors. Again liquid SO_2, which Walden[1] has shown to yield excellent conducting solutions, has a low dielectric constant[2] that would not lead one to expect such a behavior. The dielectric constant of liquid HCN was found by Schlundt[3] to be 95; this would lead one to expect this solvent to have a dissociating power greater than that of water. Preliminary tests which Mr. Schlundt and I have made show that solutions in liquid HCN are very much poorer conductors of electricity than corresponding aqueous solutions.[4] On the other hand I have found that amyl amine with a specific inductive capacity of the order of that of chloroform[5] yields fairly good conducting solutions. More striking proofs that the Nernst–Thomson rule is untenable could hardly be produced.[6] The fact that the Nernst–Thomson rule can not be maintained takes away another pillar upon which the dissociation theory has been resting.

That the "dissociating power" of solvents is dependent upon the polymerization of their molecules, as claimed by Dutoit and Aston, is not in harmony with the facts in many cases, has clearly been shown by Kahlenberg and Lincoln.[7] Again it has been maintained by Brühl[8] that "dissociating power" is pos-

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[1] l. c.

[2] The exact value has been determined in this laboratory by Mr. Schlundt who will report upon the same in connection with numerous measurements made on other solvents, among which are practically all the solvents investigated by Walden, l. c. Some older determinations of the dielectric constant of SO_2 have been found in the literature by Mr. Schlundt, which he will present in connection with his own work.

[3] l. c.

[4] We hope soon to be able to publish exact conductivity measurements of solutions in liquid HCN and also of solutions in liquid cyanogen.

[5] The exact value of the dielectric constant of amyl amine will be reported by Mr. Schlundt, whose list of determinations includes a fairly complete series of the substituted ammonias of both the fatty and aromatic series.

[6] Nernst himself (Theoretische Chemie, 3d Edition, p. 365) has realized the difficulty of harmonizing his rule with the far less striking instance that NaCl, KBr, etc., in formic acid (dielectric constant 62) solutions conduct almost as well as the corresponding aqueous solutions, in which connection he remarks that other "specific influences" come into play. He states, "Wahrscheinlich steht hier in erster Linie eine Association der Ionen mit Molekülen des Lösungsmittels". It is interesting to compare in this connection the treatment which the hydrate theory receives at the hands of the same writer, page 491.

[7] l. c.

[8] Zeit. phys. Chem. 18, 514 (1895). Ibid. 27, 317 (1898). Berichte deut. chem. Ges. 30, 163 (1897).

sessed by such solvents as are unsaturated in character. It has been shown in this connection[1] that Brühl's position is untenable, inasmuch as some solvents, which according to Brühl's view are unsaturated, and of which Brühl had predicted that they would yield conducting solutions, were found to yield solutions of high resistance. Later Brühl[2] has entered the objection that he did not mean to assert that whenever a solvent possesses spare valences it must necessarily yield conducting solutions. In other words, he claims that he did not mean to assert the converse of his original statement. Brühl cites in this connection that the statement, that whenever a compound is optically active it possesses an assymetric carbon atom, is also not necessarily true when taken conversely. He apparently forgets, however, that in our knowledge of racemic mixtures and meso compounds, we have reasons why the converse of the latter statement is not necessarily true. A corresponding reason why his own statement should not hold in the converse has, however, not been furnished by Brühl.

The theory of electrolytic dissociation is at present at its best in explaining the phenomena of actual electrolysis. But it must nevertheless be admitted that there are important phenomena of electrolysis which the theory does not explain satisfactorily. Thus if when, for example, a silver solution is electrolyzed, the process consists in each case of neutralizing the positive charge residing on silver ions (as far as the process at the cathode is concerned), as the theory claims, why do we always get poorly adhering crystalline deposits from certain solutions and dense, well-adhering deposits from others, the potential and the current density being the same? The writer has also observed certain phenomena which appear to him to be incompatible with the idea that during the process of electrolysis there is a regular procession of charged, oriented, material particles in the solution. The study along this line is being pursued further and it is hoped that the results may be ready for publication at some date in the near future. The study of the

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[1] Kahlenberg and Lincoln, l. c.
[2] Zeit. phys. Chem. 30, 1 (1899).

changes of concentration that take place around the electrodes in the electrolysis of non-aqueous solutions promises to yield results of unusual interest, especially as bearing upon the value of the dissociation theory in interpreting electrolytic phenomena. Since the time when Hittorf[1] determined the migration numbers of CdI_2, ZnI_2 and $ZnCl_2$ in absolute alcohol and those of CdI_2 in amyl alcohol, this field has not been cultivated. Now we know of a number of fairly good and some cases of excellently conducting non-aqueous solutions, in which the migration numbers await determination—work begun in this laboratory.

It might not be superfluous to recall in connection with the claim that thermodynamics requires the dissociation theory, that Clausius, who showed the discrepancy between the Grotthus theory and thermodynamics, did not find it necessary to put forth such a radical hypothesis as that of Arrhenius. Again, Hittorf on the basis of his studies of the migration of the ions evidently did not think it necessary to frame a theory giving the term ion the meaning that it now has. Finally let the reader try to recall any real marked improvements or discoveries in the realm of electrolysis which are directly traceable to the influence of the dissociation theory. The function of E. M. F. in electrolysis, especially in electrolytic separations, has been more strongly emphasized, but that is really about all. The importance of current density was early pointed out by Bunsen, and as far as the influence of the temperature of the electrolyte upon the mechanical and chemical character of the deposit is concerned, we are still upon an empirical basis as before. It is very significant, for instance, that in the latest edition of his work on quantitative analysis by electrolysis, Classen has devoted about four pages of the introductory part of the book to the ionic theory, and after that in the main body of the book we read nothing more of that theory; the preparation of the solutions from which to get suitable deposits is very much upon the same empirical basis as ever. And it is also safe to say that electrolysis as used in the arts has not received much help from the theory of Arrhenius.

[1] l. c.

The dissociation theory has led to Nernst's theory of the E. M. F. of galvanic cells, which has already been referred to above. This theory is an attempt to explain the difference of potential between two electrolytes and to account for the difference of potential between an electrode and an electrolyte, and this not only qualitatively but also quantitatively. Nernst's theory assumes that metals have a certain tendency to pass into the ionic condition, which tendency is termed the electrolytic solution tension of the metal. That which operates against this tendency is supposed to be the osmotic pressure of the ions of the metal already present in the solution, and the difference of potential between the metal and the electrolyte is the result of the action of these two forces; on the other hand, the difference of potential between two electrolytes is ascribed to the different rates with which the charged ions move. Nernst's formula really involves the assumption that the law of mass action is applicable to electrolytes in the sense required by the dissociation theory. That the law of mass action does not hold, however, in the case of electrolytes *par excellence,* has already been mentioned. By maintaining the correctness of Nernst's formula and thus assuming that the law of mass action does hold for such electrolytes, Jahn has arrived at the conclusion (as clearly he must) that $\frac{\Lambda_v}{\Lambda_\infty}$ does not correctly represent the degree of dissociation, and that the ionic velocities vary in dilute solutions. The latter is not, in many cases at least, in harmony with the facts. Arrhenius, on the other hand, stoutly defends his original $\frac{\Lambda_v}{\Lambda_\infty}$ which of course leads to a denial of the validity of the mass law as applied to the electrolytes in question. Ostwald, too, in the new edition of his Grundriss (p. 406) clearly inclines toward maintaining the time honored $\frac{\Lambda_v}{\Lambda_\infty}$ formula. The polemical discussion between Arrhenius and Jahn is still going on in the Zeit. phys. Chem., and recently Nernst has also taken a hand in the debate. It seems at first rather deplorable that so much valuable energy is being expended in trying to de-

cide which is the correct way to calculate the degree of dissociation, regarding which there are such excellent reasons to believe that it has no counterpart in reality. Naturally then insurmountable obstacles must arise in determining the value. These polemical discussions, however, are doing considerable good in that they emphasize how inadequate the dissociation theory really is,—they represent the beginning of the end of that theory.

It is true that as soon as the theory of electrolytic dissociation is declared invalid the original difficulty with the van't Hoff theory of solutions[1] recurs, namely, the theoretical interpretation of the factor i. Whenever the factor i in the equation $PV=iRT$, is unity we have the gas equation in its simplicity as it holds for dilute solutions of the now classical cane sugar. When in any case i is less than unity and diminishes as the concentration increases, the assumption that polymerization of the dissolved molecules takes place can be made; but when i is greater than unity, dissociation must be assumed. Arrhenius assumed so-called electrolytic dissociation; from which it followed that whenever a solution conducts electrolytically it requires a corresponding factor i greater than unity,—that this is by no means always the case has been sufficiently set forth above. Again it has been shown above that, in the case of cane sugar, for instance, a factor i which increases with the concentration must be introduced. There is no other logical theoretical significance to put upon this behavior than to assume that the stronger the sugar solution is the more the solute dissociates. This conclusion is absurd,—let alone the additional fact that sugar solutions do not conduct. And cane sugar is by no means the only non-electrolyte that behaves thus. Attention has been directed to the fact that Dieterici found that the molecular lowering of the vapor tension of dextrose and urea also increases with the concentration like that of cane sugar.

I am well aware that the gas equation is supposed to hold strictly only for infinitely dilute solutions, just as it holds only

[1] Compare in this connection, Crompton's explanation, Jour. Chem. Soc. London 97, 925 (1897).

for ideal gases, and that the solutions with which Dieterici worked varied between 0.1 and 1.0 normal, and that those used in experiments detailed above frequently were much stronger than normal. That a normal solution is nevertheless for many of the practical purposes of life a rather dilute solution will hardly be disputed. No one expects the gas equation to hold strictly for a normal solution or even for one considerably more dilute; but what one has a right to expect from the modern theory of solutions is, that with increasing concentration a solution should behave at least qualitatively as a gas does with increase of pressure. And this requirement is clearly not met, since while all gases behave alike under increase of pressure (so that van der Waals has been able to express their behavior by means of his well known equation) solutions, as has been shown, often behave in a manner opposite to that of gases, and this, too, frequently in solutions that can not be termed concentrated. This demonstrates, then, that the van't Hoff law is at best only approximate and must be applied with great care. As Dieterici well says:

"Raoult hat seine Gesetze der Damfspannungs- und Gefrierpunkts-depression durchaus nicht als absolut streng gültige Naturgesetze aufgestellt, sondern als nahezu zutreffende Erfahrungssätze, welche für die Zwecke der Molekulargewichtsbestimmung genau genug sind."

We have seen above (and the literature is replete with records of facts illustrating the same point) that substances of similar chemical composition, when dissolved in the same solvent, behave similarly, as far as the change of the boiling- or freezing-points are concerned; this clearly shows that the influence of the chemical nature of the dissolved substance enters into the determination of the molecular rise of the boiling-point and the molecular lowering of the freezing-point.

In pressing the analogy between gases and solutions (which undoubtedly exists and from which at times valuable suggestions may be derived) it has often been forgotten that this is after all simply an analogy; and like other analogies it fails when carried too far. It is so easy to compare the process of dissolving a lump of sugar in a beaker of water with the expan-

sion of a gas,—the analogy is at once apparent. In seeing it with the mind's eye one abstracts from the water and centers the attention entirely on the sugar. But it must be remembered that a gas will expand readily in vacuo, and that it will mix with any other gas or mixture of gases, while on the other hand, the lump of sugar will not dissolve when, for instance, benzene or absolute alcohol is poured over it. The process of solution of a substance and the expansion of a gas, then, while possessing analogy, are in reality very different processes. And right here lies the difficulty with the theory of solutions. It neglects the all important rôle of the solvent. It fails to emphasize the fact that the process of solution takes place because of a mutual attraction between solvent and dissolved substance, and that this mutual attraction, which is a function of the chemical nature of both solvent and dissolved substance, is the essence of the so-called osmotic pressure.[1] It is true that the thermodynamic considerations of van't Hoff will hold whether the osmotic pressure be considered as the outcome of a mutual attraction of solvent and dissolved substance, or as resulting from the bombardment of the molecules of the dissolved substance against the semipermeable membrane. But if we choose to use the gas equation in working with solutions it is very evident that the factor i must never be placed equal to unity (unless direct experimental evidence justifying this step is at hand) if exact results are desired, no matter whether we work with electrolytes or non-electrolytes. The dissociation theory, as has been shown, does not furnish a satisfactory explanation of the significance of i in the case of electrolytes. This value of i varies in all cases with the nature of the solvent and also, in general, with the strength of the solution; and it does not always vary to the same extent nor even in the same sense in different solutions. It is clear then, that when the simple equation $PV=RT$ is applied to a solution, only approximate results are obtained at best, unless experimental data are at hand showing that in the particular

[1] Compare here the warning words of Lothar Meyer, in his article,—Das Wesen des osmotischen Druckes. Zeit. phys. Chem. 5, 23 (1890). Also the reply of van't Hoff, Ibid., p. 174.

case and for the particular concentration under consideration i is actually equal to unity.

It must be fully and freely admitted that the dissociation theory has done much good in stimulating research in many lines. It has been fruitful in proportion to the amount of truth contained in it. Like other theories founded upon too narrow a basis of induction, it has gradually been outgrown,—the facts are too much for it. It would be difficult of course to say of any theory—even of one long ago discarded—that it is entirely worthless, and so the writer has no inclination to make such a statement concerning the dissociation theory. And further he would not be understood as having the remotest intention to belittle in any way the work done by the enthusiastic adherents of the theory of electrolytic dissociation, for this will no doubt always form a bright page in the history of the development of chemistry and of science in general.

It is solely because of the rapid growth of the erroneous idea that the deductions drawn from the indiscriminate application of the simple gas equation to solutions and from the notion that all well known facts harmonize with the theory of electrolytic dissociation, that I have felt compelled to call attention to the real status of the experimental facts underlying these deductions. It is hoped that this will stimulate to renewed experimental activity, for surely our theory of solutions leaves much to be desired. The analogy between gases and solutions does not help us to understand even moderately concentrated solutions; and whenever experimental work on such solutions is done, the assumption that there is chemical union between solvent and dissolved substance calls for recognition. That there is chemical union between solvent and dissolved substance, in many cases at least, there can be no doubt; and as for the osmotic pressure, the outcome of that mutual attraction between solvent and dissolved substance, its various excentricities and caprices, as exhibited even in moderately concentrated solutions, show clearly that it is closely related to, if not essentially identical with, chemical affinity. Our hope in the study of solutions lies in the recognition of this. The problem of solutions is pre-

eminently one for the chemist. Each solution will have to be examined separately and then it will appear that chemically analogous solutes in the same solvent will have a similar behavior, the closeness of the agreement being determined by the degree of the analogy; and finally from such a study of solutions, which can and should begin with the most concentrated, the behavior of the most dilute solutions will appear as a limiting case,—and then we shall see the present theory of solutions in its true relation to the facts. And finally, as far as the answer to the question,—What must be the relation between solvent and dissolved substance in order that the resulting solutions may conduct electricity?[1]—is concerned, we are unfortunately as yet in the dark; just as we do not know why certain solids conduct electricity and others do not. The essence of electrical conduction in electrolytes and that in metals is, after all, not so radically different as is frequently supposed. The further experimental investigation of the general problem of electrical conduction will, let us hope, ere long give us the true key to the situation.

Laboratory of Physical Chemistry,
University of Wisconsin,
Madison, May, 1901.

[1]The investigation of D. Konowalow [Wied. Ann. 49, 733 (1893)] are of special interest in this connection.

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BULLETIN OF THE UNIVERSITY OF WISCONSIN

NO. 49

SCIENCE SERIES, VOL 2, NO. 6, PP. 353-389

ON THE DIELECTRIC CONSTANTS OF PURE SOLVENTS

BY

HERMAN SCHLUNDT, PH. D.

Instructor in General and Physical Chemistry

Published bi-monthly by authority of law with the approval of the Regents of the University and entered at the post office at Madison as second-class matter

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ON THE DIELECTRIC CONSTANTS OF PURE SOLVENTS.

Introduction.

In 1893 Nernst,[1] from theoretical considerations based upon the theory of electrolytic dissociation, deduced his well known rule, that—other things being equal—the greater the dielectric constant of a medium the greater is its dissociating power. In the same year J. J. Thomson[2] also pointed out this relation, saying that if we accept the view that the forces between the atoms are electrical in their origin then the effect of surrounding the molecules of a substance by a medium possessing a very high dielectric constant like water, would be to practically dissociate them. According to Nernst, proportionality between the dielectric constant and dissociating power need not necessarily exist, but a close parallelism between the two doubtless prevails. He adds that other factors besides the dielectric constant doubtless exist, which probably influence the dissociating power of the solvent. The experimental facts, Nernst[3] says, show beyond a doubt that a marked parallelism exists between the dissociating power and the dielectric constant. Exceptions to the rule he explains by assuming the existence of specific influences, of which the association of the ions with the molecules of the solvent is probably of prime importance.

The existing experimental data at the time the above relation between the dielectric constant and dissociating power was pointed out accorded well with it, and subsequent investigations furnished numerous additional examples in support of it. But

[1] Göttinger Nachrichten No. 12, (1893); Zeit. phys. Chem. **13**, 531, (1894).
[2] Phil. Mag. **36**, 320. (1893).
[3] Theoretische Chemie p. 365. (Dritte Auflage).

exceptions also appeared which point to a marked specific influence of the solvent. Some of these exceptions are noted and considered in another part of this paper.

The following table taken from Nernst's[1] Theoretical Chemistry illustrates the general parallelism between the dielectric constant and the dissociating power.

TABLE I.

Medium.	Dielectric Constant.	Electrolytic Dissociation.
Gas	1.0	Not perceptible at ordinary temperatures.
Benzene	2.3	Exceedingly low; but distinctly perceptible conductivity indicates traces of dissociation.
Ether	4.1	Perceptible conductivity of dissolved electrolytes.
Alcohol	25	Dissociation quite marked.
Formic acid	62	Marked dissociation of dissolved salts.
Water	80	Very marked dissociation.

Since the formulation of the Nernst–Thomson rule excellent new methods for determining dielectric constants have been devised by Thwing,[2] Nernst,[3] and Drude;[4] and these investigators have measured the dielectric constants of a number of substances. The pupils of Nernst, and of Drude, and others have elaborated, modified and perfected these methods, so that the determination of dielectric constants at ordinary temperatures is now a comparatively simple operation. During this period the electrical conductivity of non-aqueous solutions has also received considerable study, and the dissociating power of various solvents, which yield conducting solutions, has moreover been investigated by means of cryoscopic and boiling-point determinations. The selected examples given in the following table will serve to show that various other solvents besides water possess ionizing power in a very marked degree. Under V, in the third

[1] P. 365, third edition. (1900).
[2] Phys. Review, 2, 35. (1894). Also Zeit. phys. Chem. 14, 286. (1894).
[3] Zeit. phys. Chem. 14, 622. (1894).
[4] Zeit. phys. Chem. 23, 267. (1897).

column, the volume in liters is given in which one gram molecule of substance is dissolved; and the next column gives the corresponding molecular conductivity, while the fifth column gives the temperature at which the measurements were made.

TABLE II.

Solvent	Solute	V	Uv	t°C	Observer
Water	KI	2	99.7	18	Kohlrausch [1])
		100	116.1		
		1000	120.3		
Methyl alcohol	LiCl	11.7	40.1	18	Völlmer [2])
		117.4	57.5		
		1174.0	65.3		
Formic acid	KCl	32	40.7	25	Zanninovich-Tessarin [3])
		1024	57.8		
Liquid ammonia	K Br	301.9	210.6	−38	Franklin and Kraus [4])
		1354	272.9		
		65040	340.2		
Liqnid sulphur dioxide	$N(C_2H_5)_4I$	16	43.1	0	Walden [5])
		128	51.6		
		1024	54.8		
Acetone	KI	144.7	109.4	18	St. v. Lascynski [6])
		1157.6	145.8		
Benzonitrile	$Ag NO_3$	9.43	5.2	25	Lincoln [7])
		151.96	16.4		
Acetonitrile	$Ag NO_3$	8	54.5	25	Dutoit and Friderich [8])
		128	118.3		
Pyridine	NH_4I	79	16.7	25	St. v. Lascynski and St. v. Gorski [9])
		1264.32	36.9		
Phosphorus oxy-chloride	$S(CH_3)_3I$	204	26.4	25	Walden [10])
		1224	38.2		
Arsenic trichloride	$S(CH_3)_3I$	250	51.4	25	Walden [10])
		1500	66 6		

[1] Wied. Ann. 26, 161. (1885).
[2] Wied. Ann. 52, 328. (1894).
[3] Zeit. phys. Chem. 19, 251. (1896).
[4] Am. Chem. Jour. 23, p. 288. (1900).
[5] Ber. d. Deutsch. Chem. Gesel. 32, 2862. (1899).
[6] Zeit. Elektrochem. 2, 55. (1895).
[7] Jour. Phys. Chem. 3, 457. (1899).
[8] Bull. Soc. Chem. [3] 19, 327. (1898).
[9] Zeit. Elektrochem. 4, 290. (1897).
[10] Zeit. anorg. Chem. 25, 209. (1900).

The dielectric constants of the last four solvents given in the table have, to my knowledge, not been determined before. That these solvents possess marked dissociating power the results given in the table clearly show. Hence by the Nernst–Thomson rule they should have high values for their dielectric constants. The dielectric constant of benzonitrile was measured by Drude,[1] and found to be 26.0 at 21° C. Drude also measured the dielectric constant of benzyl cyanide, but his extensive investigation does not include any of the nitriles of the aliphatic series. The dielectric constant of liquid ammonia was measured by Goodwin and Thompson[2] who found the value 22.0 at —34° C., and by Coolidge,[3] who gives the value 16.2 at 14° C. The substituted ammonias, Prof. Kahlenberg[4] finds, also yield good conducting solutions. In view of the great dissociating power of the nitriles and the substituted ammonias it seemed of special interest to determine the dielectric constants of these compounds, and at Prof. Kahlenberg's suggestion this work was undertaken. The investigation also embraces a number of other organic compounds containing nitrogen, and includes most of the inorganic solvents in which Walden[5] made electrical conductivity measurements.

During the progress of his researches on non-aqueous solutions, Prof. Kahlenberg collected a choice lot of preparations which he kindly placed at my disposal. This greatly facilitated the experimental part of my work, and I desire to express to him my thanks for this favor.

Method and Apparatus.

In measuring the dielectric constants the method devised and elaborated by Drude[6] was used. It is unnecessary for me to give a complete description of this method and of the details of

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[1] Zeit. phys. Chem. 23, 309. (1897).
[2] Phys. Rev. 8, 38. (1899).
[3] Wied. Ann. 69, 140. (1899).
[4] Jour. phys. Chem. June (1901).
[5] Ber. d. Deutsch. Chem. Gesel. 32, 2862, (1899). Zeit. anorg. Chem. 25, 209. (1900).
[6] Zeit. phys. Chem. 23; 267. (1897). See also Wied. Ann. 55, 633. (1895); 58, 1; 59, 17 (1896); 60, 28, 500, (1897).

the apparatus employed. The reader is referred to Drude's original articles, after reading which the additional remarks on the method contained in the paragraphs that now follow will be much better understood.

The apparatus used for these measurements was a trifle larger than the one described by Drude. The wave-length of the electrical waves in the two parallel wires in air was about 84 cm. as compared with 74 cm. of the apparatus employed by Drude. A vacuum tube containing hydrogen was used to determine the settings for maximum resonance. It served very well indeed for this purpose.

Of the two methods described by Drude the first is the more accurate, but it necessitates the use of comparatively large quantities of substance, at least 200 cc, which, in most cases, were not available. Moreover, the poisonous nature of many of the compounds made it desirable to work with small quantities which could be kept in a closed cell while under investigation. Drude's "second" method, although less accurate, was therefore chosen. This method enables one to operate with less than a cubic centimeter of solvent and gives results accurate to within two per cent. In this method the substance to be measured is introduced into a small condenser which is placed in the secondary circuit. The length of the secondary circuit is then adjusted for maximum resonance. The dielectric constant corresponding to the length noted is found from a calibration curve representing the results obtained in calibrating the apparatus for the particular condenser.

Four cells similar in form but of different capacities served as condensers. The apparatus was calibrated for each cell with the liquids recommended by Drude, namely: benzene, acetone, water, mixtures of benzene and acetone, and mixtures of acetone and water. Seventeen liquids whose dielectric constants range from 2.26 to 80.9 at 19° C. were prepared. The benzene used for these calibrating solutions was Kahlbaum's thiophene free preparation, purified by crystallization. Its boiling point was 79.2° C. under 744.6 mm of pressure. The acetone was like-

wise Kahlbaum's preparation—it was prepared from the bisulphite compound. It boiled at 55.7° C. under 746 mm of pressure. The water used had a specific conductivity of 3.6×10^{-6}.

In calibrating, the "zero" of the apparatus, obtained by placing a straight piece of copper wire in place of the cell, was frequently redetermined, as a change in the position of certain parts of the apparatus may produce a change of the "zero" point. This precaution was also taken whenever solvents of unknown dielectric constants were under examination. As a check on any change in the capacity of the cells, the calibrating liquids whose dielectric constants were nearest in value to that found for the solvent under examination were introduced into the cell and the settings for maximum resonance determined. In this way any change in the position of the condenser plates could be readily detected. This procedure also gives all the necessary data for calculating the dielectric constant according to the formula given by Drude:[1]

$$D = D_1 + (D_2 - D_1)\frac{\cot\frac{2\pi l}{\lambda} - \cot\frac{2\pi l_1}{\lambda}}{\cot\frac{2\pi l_2}{\lambda} - \cot\frac{2\pi l_1}{\lambda}}$$

in which λ is the wave-length of the electric waves in air, D is the dielectric constant sought, l is the setting for maximum resonance when the cell contains the solvent whose dielectric constant is sought; D_1, l_1 and D_2, l_2, are the dielectric constants and settings of the calibrating solutions. In working with pyridine the dielectric constant was calculated by this formula using 84 cm for λ. The value found was the same as the value obtained with the aid of the calibration curve.

From 10 to 30 settings for maximum resonance were made for each solvent examined, and the average of these was the value used for obtaining the dielectric constant.

The methods of dehydrating and rectifying the various solvents will be found under the head of each particular solvent in the statement of results given below.

A series of trial experiments was at first made with the appa-

[1] Zeit. phys. Chem. 23, 309. (1897).

ratus in order to test it thoroughly. The dielectric constants of ethyl ether, chloroform, ethyl benzoate, salicylic aldehyde, benzonitrile, and nitrobenzene were measured, and the results obtained agreed very well with those given by Drude. It is therefore entirely superfluous to again report the numerical results obtained for these substances.

Experimental Results.

THE NITRILES.

The dielectric constants of the following aliphatic nitriles were measured: Hydrocyanic acid, acetonitrile, propionitrile, butyronitrile, iso-propyl cyanide, valeronitrile, iso-butyl cyanide, capronitrile, and ethylene cyanide. In the aromatic series, benzonitrile, benzyl cyanide, ortho-toluonitrile, mandelic nitrile, and α- and β- naphthonitriles were measured.

Hydrocyanic Acid.—The sample of hydrocyanic acid used was prepared in the usual way by slowly adding a strong aqueous solution of potassium cyanide to sulphuric acid of Sp. Gr. 1.25 in a retort connected with a reflux condenser kept at 30° C. The gas was then dried at 30° C. by passing it through a series of three large U tubes, kept at 30° C., and containing fused calcium chloride. The gas was condensed in a tube provided with glass stopcocks, suspended in a bath at 0°. A colorless liquid was thus obtained which left no residue upon evaporation. Some of the liquid was introduced into the cell adapted for the measurement of liquids having a high dielectric constant. The cell was securely stoppered and the measurements were made at 21° C. No appreciable absorption was observed, the position for maximum resonance being about as well defined as in the case of acetone. The D. C.[1] found is higher than the D. C. of water. This necessitated an extrapolation of the calibration curve in order to get an approximate value. The D. C. obtained in this way is 95.0 ± 3.5 After this exceedingly high result had been obtained a second sample of hydrocyanic

[1] The abbreviation D. C, is used for dielectric constant in the presentation of the results.

acid was prepared by redistilling the first sample from a water-bath kept at 30° C. The gas was again passed through the drying tubes and condensed as before. Measurements with this sample gave the same readings for maximum resonance as in the first case. The temperature coefficient is negative, but it was not accurately determined.

Acetonitrile.—The sample of acetonitrile first measured was obtained by distilling a sample of Kahlbaum's make. Its boiling point was very constant, being 80.9° C. under a pressure of 745 mm.. The average of four determinations gave the value 36.5 for the D. C. at 21° C.

A second sample, prepared by Prof. Kahlenberg from the Kahlbaum preparation by dehydrating it with phosphorus pentoxide, and redistilling twice, was measured. Its boiling point was 80.7 under a pressure of 749 mm. The measurements were made at 22° and gave the same result as was obtained with the first sample.

A third sample, also furnished by Prof. Kahlenberg, was finally measured. This sample was twice dehydrated with larger quantities of phosphorus pentoxide than were used in the previous case, and was distilled from phosphorus pentoxide. It had a boiling point of 80.2° C. under a pressure of 736 mm. The D. C. was calculated by the formula previously given, and found to be 36.1 at 21° C.

Propionitrile.—This sample was Schuchardt's preparation. Its boiling point was 94.6° under a pressure of 749 mm. The average of four determinations at different times gave the value 26.5 for the D. C. at 22° C. The absorption was slight.

Butyronitrile.—The sample tested was Schuchardt's preparation. It was redistilled from calcium chloride. Its boiling point was 116.5° to 118° C. under 742 mm of pressure. The average of three different determinations is 20.3 at 21° C.

Iso-propylcyanide.—The sample was Schuchardt's preparation. It was dehydrated with calcium chloride and redistilled. Its boiling point was 106°–107° C. under 744 mm of pressure.

The average of three determinations gave the value 20.4 for its D. C. at 24° C.

Valeronitrile (normal).—The sample was obtained from Schuchardt. It was redistilled from calcium chloride, and the portion which distilled between 137° and 139° C., under 743 mm of pressure was taken for the measurements. The D. C. was found to be 17.4° at 31° C.

Iso-butylcyanide.—The sample was Schuchardt's make; it was redistilled from calcium chloride, and the portion distilling between 129° and 130.5° C., under a pressure of 742 mm was taken for the measurements. Its D. C. was found to be 17.95 at 22° C.

Capronitrile.—The sample used was obtained from Schuchardt. It was redistilled from calcium chloride, and the portion distilled between 153°–154.2° C., under 743 mm pressure, was taken for the measurements. Its D. C. was found to be 15.5 at 22° C. The higher members of the series show a slight amount of absorption, but the maximum resonance is still well enough defined without increasing the intensity of the oscillations in the secondary circuit.

Ethylene Cyanide.—The sample of succinic acid nitrile was of Schuchardt's make. It was treated with fused calcium chloride, filtered and redistilled twice under diminished pressure. Its boiling point was 168° C. under a pressure of 28 mm. A solid, almost colorless, amorphous compound was thus obtained which melted at 54° C. Its D. C. was measured in the form of cell used by Drude[1] for the measurement of substances at higher temperatures. During the measurements the cell was kept in an oil-bath of the form figured and described by Coolidge.[2] The bath was attached to the ebonite slide by means of a small spring clamp. The temperature was kept at 60° ± 1° during the measurements of the liquid ethylene cyanide. The average of three determinations gave the value 61.2 for its D. C. The D. C. of the solid compound was also determined. Three determi-

[1] See Fig. 7, p. 285, Zeit. phys. Chem. 23. (1897).
[2] Wied. Ann. 69, 133. (1899).

nations averaged 65.3 at 23° C. No sudden change in the D. C. was observed at the melting point. The absorption of the solid ethylene cyanide was very slight; but the liquid sample did not show a well defined maximum, which was found to be due to its greater conductivity. The qualitative measurements of its resistance show that the temperature has a great influence on the resistance. At room temperatures the resistance is about twenty times as great as it is at 60° C.; but no sudden change in the resistance was observed at the melting point.

Toluonitrile (ortho.).—Schuchardt's preparation was redistilled from calcium chloride. A straw colored distillate, boiling at 200° — 201° C. under a pressure of 733 mm. was thus obtained. It D. C. was found to be 18.5 at 23° C. It showed slight absorption.

α-Naphthonitrile.—Schuchardt's preparation was redistilled under diminished pressure. Its melting point was 37° C.; but it is easily kept in a liquid state at 20° C. when the solid phase is not present. Its dielectric constant was determined in the form of cell adapted for measurements at higher temperatures, and the following values were found for the liquid sample.

D. C. = 16.0 at 70° C.
D. C. = 17.9 at 42° C.
D. C. = 19.2 at 22° C.

The position for maximum resonance was about as well defined as for nitro-benzene whose absorption index Drude[1] places at 0.05. The D. C. of the solid sample was found to be 6.3 at 21° C.; but this value is only approximate, for the position for maximum resonance was not well defined.

β-Naphthonitrile.—Thes ample used for the measurements was obtained by distilling Schuchardt's preparation under diminished pressure. Its boiling point was 190° C. under 35 mm. of pressure, and its melting point was 64° C. The D. C. of the liquid was found to be 16.9 at 70° C., and for the solid the value 4.3 at 23° C. was obtained, the position for maximum resonance being well defined in both the solid and the liquid samples.

[1] Zeit. phys. Chem. **23**, 309. (1897).

Mandelic Nitrile.—The preparation from which the sample was obtained was of Schuchardt's manufacture. It showed decided signs of decomposition, being of a dark brown color and somewhat syrupy. It was dehydrated with fused calcium chloride, was filtered and distilled under diminished pressure, and the sample thus obtained was redistilled. Its boiling point was 94° C. under a pressure of 50 mm. A mobile, colorless liquid was thus obtained whose specific conductivity was found to be 2.2×10^{-10} reciprocal ohms. Its dielectric constant was found to be 17.82 at 23° C. An absorption of about the same order as that of nitrobenzene was observed. Its absorption index was also determined by the method outlined by Drude.[1] The value obtained in this way was .045, which agrees very well with that of nitrobenzene which Drude places at .05. Drude has found that this anomalous absorption is characteristic of compounds containing hydroxyl.

THE SUBSTITUTED AMMONIAS.

The amines whose dielectric constants were measured are enumerated in Table III. The samples used were Schuchardt's preparations with the exception of the two toluidines and the xylidine which were of Trommsdorff's manufacture. Each sample, except methylamine, was dehydrated with fused potassium hydroxide and then distilled; and in many cases the distillate was again treated with fused potash and redistilled. The sample of methylamine was doubtless impure for, upon evaporation it left a residue, and it did not yield a well defined position for maximum resonance, while with all the other samples well defined maxima were observed. Hence the value found for the D. C. of methylamine is doubtless too high.

The third column in the following table gives the boiling point of the samples taken for the measurements, and the fourth column indicates the corresponding barometric pressure, while the last column gives the temperature at which the D. C. was measured.

[1] Zeit. phys. Chem. 23, pp. 292-297. (1897).

TABLE III.

Name.	Formula.	B. P.	P.	D. C.	t°C
Methylamine	CH_3NH_2	....	....	< 10.5	21
Ethylamine	$C_2H_5NH_2$	< 17.5	752	6.17	21
Iso-propylamine	$\left\{\begin{matrix}CH_3\\CH_3\end{matrix}\right\}CH\,NH_2$	36	750	5.45	20
Butylamine (n)	$C_4H_9NH_2$	76–77	740	5.30	21
Iso-butylamine	$\left\{\begin{matrix}CH_3\\CH_3\end{matrix}\right\}CH.CH_2NH_2$	68	745.2	4.43	21
Amylamine	$C_5H_{11}NH_2$	94–95	740.4	4.50	22
Di-ethylamine	$(C_2H_5)_2NH$	54.5	733.4	3.58	21
Di-propylamine	$(C_3H_7)_2NH$	108–108.5	745.5	2.90	22
Di-iso-butylamine	$(C_4H_9)_2NH$	134.5	735	2.65	22
Trimethylamine	$N(CH_3)_3$	< 8°	750	2.95	4
Aniline	$C_6H_5NH_2$	179.4	741	7.2	19
Toluidine (o)	$C_6H_4\left\{\begin{matrix}NH_2\ (1)\\CH_3\ (2)\end{matrix}\right\}$	194.5	738	5.93	20
Toluidine (m)	$C_6H_4\left\{\begin{matrix}NH_2\ (1)\\CH_3\ (3)\end{matrix}\right\}$	194.2	738.2	5.95	20
Xylidine 1:3:4	$C_6H_3\left\{\begin{matrix}CH_3\ 1\\CH_3\ 3\\NH_2\ 4\end{matrix}\right\}$	209.5	737.0	4.90	20
Mono-methylaniline	$C_6H_5NH\,CH_3$	189.4	740.5	5.8	20
Di-methylaniline	$C_6H_5N(CH_3)_2$	191.5	735	5.07	20
Di-benzylamine	$(C_7H_7)_2NH$	200	40	3.55	20

MISCELLANEOUS ORGANIC COMPOUNDS.

Pyridine.—The sample was Schuchardt's preparation. It was redistilled and found to boil from 115.5° to 117° C. under 745 mm. of pressure. With this several measurements were made, the average of the results for the D. C. being 12.35 at 21° C.

A second sample was furnished by Prof. Kahlenberg. Kahlbaum's best preparation was carefully purified according to the method given by Ladenburg.[1] The portion boiling at 114° C.

[1] Liebig Ann. 247, 1. (1888).

under 744.6 mm. of pressure was used for the measurements. The D. C. was found to be 12.55 at 20° C., a result which agrees well with the foregoing. The settings for maximum resonance were well defined.

α-Picoline.—The sample was Schuchardt's preparation. It was treated with fused calcium chloride, and redistilled. The boiling point of the portion taken for the measurements was 128.5° — 129.5° C. at 736 mm. of pressure. The value found for the D. C. is 9.8 at 20° C.

The unpurified sample of pyridine, it will be noted, gave a slightly lower D. C. than the purified sample. The former very likely contained a slight amount of picoline.

Quinoline.—Two samples of quinoline were measured. The first was obtained by redistilling Schuchardt's preparation marked, "Quinoline from Coal Tar." The portion which distilled at 232° C. under 746 mm. of pressure was measured. Its D. C. was found to be 8.7 at 22° C.

The second sample was a synthetic preparation, made by Messrs. Maxon and Thomas in this laboratory according to the method of Skraup. The boiling point of the sample measured was 232° C. under 746 mm. of pressure. Its dielectric constant was found to be 8.9 at 20.5° C. The agreement is close enough to fall within the limit of error. The absorption is slight. These values of the D. C. agree well with the result, 8.9, obtained by Turner[1] who worked with Nernst's apparatus.

Piperidine.—The sample was E. de Haën's preparation. It was redistilled and the portion distilling between 105.5° and 107.0° C. under a pressure of 745 mm. was used for the measurements. It was an almost colorless liquid and showed no absorption. The value found for its D. C. was 5.8 at 22° C.

Carbon dichloride.—The sample was of Schuchardt's make. Its boiling-point was 118° at 726.5 mm. of pressure. The value 2.46 was found for its D. C. at 21° C.

Nitromethane.—Schuchardt's preparation was treated with fused calcium chloride and redistilled. Its boiling-point was

[1] Zeit. phys. Chem. 35, 385. (1900).

99.9° under a pressure of 738.4 mm. The dielectric constant found was 40.4 at 19° C. Thwing[1] gives the value 56.36 at 15° C.

Nitroethane.—Schuchardt's preparation was dehydrated and rectified as in the case of nitromethane. Its boiling-point was 110.5° C. at 738.3 mm. of pressure. The value of its D. C. was found to be 29.5 at 18° C.

Methyl Nitrate.—The sample of methyl nitrate used for the measurements was prepared from Kahlbaum's best methyl alcohol by treating it with nitric acid according to the method of J. Lea.[2] The sample was washed with water containing a small amount of sodium carbonate, and was dehydrated with fused calcium chloride and finally distilled from a waterbath. Its boiling point was 64.4° C. at 730.2 mm. of pressure. The value 23.5 was found for its D. C. at 18° C. No absorption was observed.

Ethyl Nitrate.—Schuchardt's preparation was washed with water containing a trace of sodium carbonate to remove traces of nitric acid and alcohol. It was then dried with fused calcium chloride and redistilled twice. The boiling point was 86.1° at 729.4 mm. of pressure. The average of three determinations gave the value 18.3 at 18° C. Thwing found the value 17.72 at 15° and Drude found 19.6 for the D. C. of this compound at 17° C.

Propyl Nitrate.—This compound was prepared according to the method of Wallach and Schulze.[3] The propyl alcohol used for its preparation was redistilled. Its boiling-point was 95.8° under a pressure of 752 mm. The sample of propyl nitrate was dehydrated and rectified as described for ethyl nitrate. Its boiling point was 108.5° C. under a pressure of 738.5 mm. The value 13.9 was obtained for its D. C. at 18° C.

Iso-butyl Nitrate.—Schuchardt's preparation was redistilled. Its boiling-point was 120.0° under 738.2 mm. of pressure.

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[1] Physical Review. 2, 35. (1894).
[2] See Beilstein, Handbuch der Organischen Chemie. (Third edition) Vol. I, p. 324.
[3] Ber. d. Deutsch. Chem. Gesel. 14, 422.

One series of measurements was made which gave the value 11.7 for its D. C. at 19° C.

Iso-propyl Nitrite.—A sample of iso-propyl nitrite, probably not entirely free from nitrous acid, was measured. The value 11.5 was found for its D. C. at 19° C.

Ethyl Urethane.—The sample used for the measurements was kindly furnished by the School of Pharmacy of this University. Its melting-point was 48° C. The value found for the D. C. of the liquid compound at 60° was 13.6; the solid form gave the value 3.18 at 23° C.

Amylsulph-hydrate.—The boiling point of the sample was 116.5° C. under 752 mm. of pressure. The D. C. found was 4.35 at 22° C.

INORGANIC SOLVENTS.

Phosphorus Trichloride.—The sample used was of Kahlbaum's manufacture. It was redistilled, boiling at 74.1° C. under a pressure of 740 mm. The average of two determinations gave the value 3.36 for its D. C. at 22° C. No absorption was observed.

Arsenic Trichloride.—The sample which served for the measurements had been prepared in this laboratory by Dr. Lincoln. It was dried with fused calcium chloride and was redistilled. The sample used boiled from 127° — 128° C. under 740 mm. of pressure. The value 12.35 was obtained for its D. C. at 21° C. Slight absorption which was doubtless due to conduction was observed.

Antimony Trichloride.—The sample used for the measurements conducted about as well in the fused state, at 70° C., as a fiftieth normal sodium choride solution. The position for maximum resonance was still well enough defined without increasing the intensity of the oscillations in the secondary circuit, but the absorption was more marked than with arsenic trichloride. Hence it seemed advisable to determine the D. C. by the method outlined by Drude[1] for substances which show absorp-

[1] See Drude Zeit. phys. Chem. 23, pp. 294–297.

tion. The value thus obtained was 33.2 at 75° C. For the solid compound the value 5.4 was found at 18° C.

Antimony Pentachloride.—The sample used was E. de Haën's preparation. It was found securely stoppered and hence was not rectified. The value 3.78 was obtained for its D. C. at 21.5° C.

Stannic chloride.—Kahlbaum's preparation was redistilled. Its boiling-point was 117.5° C. under 750 mm. of pressure. The value found for its D. C. is 3.2 at 22° C.

Sulphur Mono-chloride.—The sample used for the measurements had been prepared in this laboratory by Mr. Harry Eggers. It was redistilled and found to boil at 136.2° under 738 mm. of pressure. The value 4.8 was found for its D. C. at 22° C.

Sulphur Trioxide.—A sample of Kahlbaum's sulphur trioxide was measured in both the solid and liquid states. The value 3.56 was obtained for the D. C. of the liquid sample at 21°, and 3.64 for the solid at 19° C.

Phosphorus Oxychloride.—The sample used for the measurements was prepared according to the method described by Gerhardt.[1] About 150g of phosphorus pentachloride was mixed with one-half its weight of dry oxalic acid in a retort and heated gently. The distillate thus obtained was redistilled and found to boil at 105.1° under a pressure of 739.2 mm. The value obtained for its D. C. was 13.9 at 22° C.

Sulphurylchloride (SO_2Cl_2).—This compound was prepared by the method of Schulze.[2] A quality of camphor was liquefied by passing dry sulphur dioxide into the containing vessel. Dry chlorine gas was then passed into the liquid and the current of sulphur dioxide was also continued. In the presence of the camphor chlorine and sulphur dioxide unite to form sulphuryl-chloride. After several distillations a product boiling at 68.4° under 740.2 mm. of pressure was obtained. The value 9.15 was found for its D. C. at 22° C.

[1] Ann. Chim. et de Phys. [3] **44**, 102.

[2] Jour. prakt. Chem. **23**, 351.

Thionyl chloride ($SOCl_2$).—The sample used for the measurements was prepared in the usual way, namely, by the reaction of dry PCl_5 with dry SO_2. [$PCl_5 + SO_2 = POCl_3 + SOCl_2$]. About 150g of PCl_5 was placed in a retort connected with a reflux condenser and a stream of SO_2 was conducted in till the PCl_5 had become liquefied; another portion of PCl_5 was then added, and the stream of SO_2 was continued. The liquid thus obtained was heated for some time, with the return condenser still attached, to free it from SO_2; and finally, by repeated fractional distillation a sample of $SOCl_2$ was obtained which had a constant boiling point of 76.8° under a pressure of 751.3 mm. The value found for its D. C. is 9.05 at 22° C. Slight absorption was observed.

Liquid Sulphur Dioxide.—A sample of liquid sulphur dioxide was measured in a sealed cell. The value found for its D. C. at 22° is 12.35. Linde,[1] by Nernst's method, found the value 14.8 at 23°, while Coolidge[2] found the value 13.75 at 14.5.° I made but one determination.

Bromine.—The sample of bromine used for the measurements was prepared by Miss Winifred Titus from potassium bromide, potassium bromate, and sulphuric acid according to the method of J. S. Stas.[3] The value 3.18 was obtained for its D. C. at 23° C. The measurements were made soon after the bromine had been introduced into the cell, so as to minimize the action of the bromine on the platinum plates.

Iodine.—Pure resublimed iodine obtained from the chemical works of de Haën at List near Hannover was once more sublimed by Prof. Kahlenberg. An attempt was made to determine its D. C. in the solid and the liquid states in a sealed cell. With the solid sample the position for maximum resonance was still fairly well defined, but after removing the iodine from the cell it was found, that the plates of the condenser were covered with a black coating, which doubtless introduced an error. Hence

[1] Wied. Ann. **56**, 546. (1895).
[2] Wied. Ann. **69**, 130. (1899).
[3] Unters. über Proport. u. Atomg. Leipzig, 1867, p. 220. See also Fehling's Handwörterbuch d. Chemie. I, p. 235.

the value 10.3, which was found for its D. C. at 23°, must be regarded as only approximate. With the liquid sample no distinct maximum resonance was obtained.

Cyanogen (Liquid).—In view of the high dielectric constant obtained for hydrocyanic acid it seemed of special interest to determine the D. C. of liquid cyanogen. Prof. Kahlenberg kindly offered to undertake the preparation of this compound with me. We evolved the cyanogen by treating a strong solution of copper sulphate with a concentrated solution of potassium cyanide. The gas was dried by passing it through two large U-tubes filled with fused calcium chloride. It was condensed by means of solid carbonic acid. The D. C. was measured in a sealed cell at 23° C. We found the value 2.52, the position for maximum resonance being well defined.

All the foregoing results are summarized in the following table, in which the abbreviations (l.) and (s.) are used for liquid and solid respectively.

TABLE IV.

Name.	Formula.	t.	D. C.
Cyanogen (l)	$(CN)_2$	23	2.52
Hydrocyanic acid (l)	HCN	21	95.
Acetonitrile	$CH_3\ CN$	21	36.4
Propionitrile	$C_2\ H_5\ CN$	22	26.5
Butyronitrile (n)	$C_3\ H_7\ CN$	21	20.3
Iso-propyl cyanide	$(CH_3)_2\ CH\ CN$	24	20.4
Valeronitrile (n)	$C_4\ H_9\ CN$	21	17.4
Iso-butyl cyanide	$(CH_3)_2\ CH\ CH_2\ CN$	22	17.95
Capronitrile	$(CH_3)_2\ CH\ CH_2\ CH_2\ CN$	22	15.5
Ethylene cyanide (s)	$C_2\ H_4\ (CN)_2$	23	65.3
Ethylene cyanide (l)	$C_2\ H_4\ (CN)_2$	60	61.2
α — Naphthonitrile (s)	$C_{10}\ H_7\ CN$	21	6.3 ?
α — Naphthonitrile (l)	$C_{10}\ H_7\ CN$	42	17.9
α — Naphthonitrile (l)	$C_{10}\ H_7\ CN$	70	16.0
β — Naphthonitrile (s)	$C_{10}\ H_7\ CN$	21	4.3
β — Naphthonitrile (l)	$C_{10}\ H_7\ CN$	70	16.9
Mandelic nitrile	$C_6\ H_5\ CH\ OH\ CN$	23	17.82

TABLE IV — Continued.

Name.	Formula.	t.	D. C.
Benzonitrile [1]	C_6H_5CN	21	26.0
Benzyl cyanide [2]	$C_6H_5CH_2CN$	21	14.9
Toluonitrile (ortho)	$C_6H_4\left\{\begin{matrix}CH_3\\CN\end{matrix}\right\}$	23°	18.4
Pyridine	C_5H_5N	21	12.4
α-Picoline	$C_5H_4NCH_3\ (\alpha)$	20	9.8
Piperidine	$C_5H_{10}NH$	22	5.8
Quinoline [3]	C_9H_7N	21	8.8
Carbon dichloride	C_2Cl_4	21	2.46
Ethyl sulph-hydrate	C_2H_5SH	22	4.35
Ethyl urethane (s)	$CO.NH_2O.C_2H_5$	23	3.18
Ethyl urethane (l)	$CO.NH_2O.C_2H_5$	60	13.6
Methylamine	CH_3NH_2	21	$<$ 10.5
Ethylamine	$C_2H_5NH_2$	21	6.17
Iso-propylamine	$(CH_3)_2CHNH_2$	20	5.45
Butylamine (n)	$C_4H_9NH_2$	21	5.30
Isobutylamine	$(CH_3)_2CHCH_2NH_2$	21	4.43
Amylamine	$C_5H_{11}NH_2$	22	4.50
Diethylamine	$(C_2H_5)_2NH$	21	3.58
Diproplyamine	$(C_3H_7)_2NH$	22	2.90
Di-isobutylamine	$[(CH_3)_2CHCH_2]_2NH$	22	2.65
Trimethylamine	$(CH_3)_3N$	24	2.95
Aniline [4]	$C_6H_5NH_2$	20	7.20
Toluidine (ortho)	$C_6H_4\left\{\begin{matrix}NH_2\\CH_3\ (0)\end{matrix}\right\}$	20	5.93
Toluidine (meta)	$C_6H_4\left\{\begin{matrix}NH_2\\CH_3\ (m)\end{matrix}\right\}$	20	5.95
Xylidine 1:3:4	$C_6H_3\left\{\begin{matrix}CH_3-1\\CH_3-3\\NH_2-4\end{matrix}\right\}$	20	4.90
Monomethylaniline	$C_6H_5NHCH_3$	20	5.8
Dimethylaniline	$C_6H_5N(CH_3)_2$	20	5.07
Dibenzylamine	$(C_6H_5)_2NH$	20	3.55
Nitromethane [5]	CH_3NO_2	19	40.4
Nitroethane	$C_2H_5NO_2$	18	29.5
Methylnitrate	CH_3NO_3	18	23.5

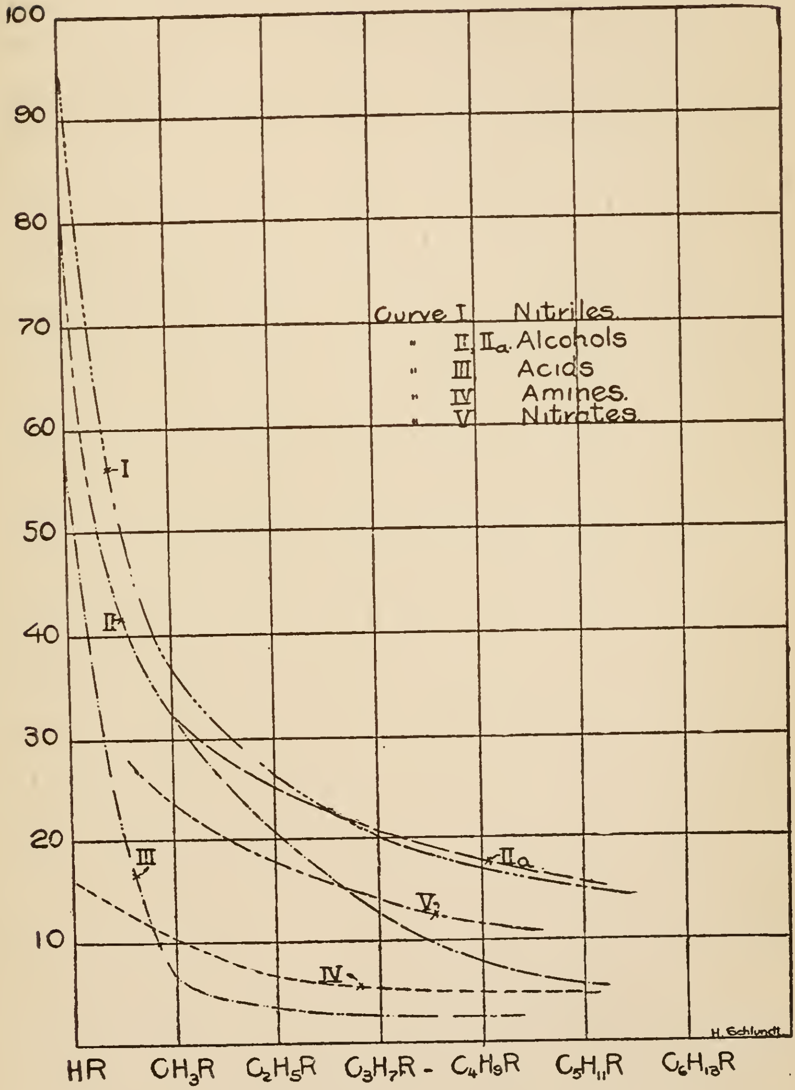
[1] Drude found 26.0 for the D. C of benzonitrile at 21°C.
[2] Drude found 15.0 for the D. C. of benzylcyanide at 19°C.
[3] Turner found 8.9 for quinoline.
[4] The value 7.15 (at 21°) was found by Drude; and 7.22 (at 15°) by Ratz. Zeit phys. Chem. **19**, 94. (1896).
[5] Thwing gives the value 56.36 at 15°.

TABLE IV — Continued.

Name.	Formula.	t.	D. C.
Ethylnitrate	$C_2 H_5 NO_3$	18	18.3
Propylnitrate	$C_3 H_7 NO_3$	18	13.9
Isobutylnitrate	$(CH_3)_2 CH CH_2 NO_3$	19	11.7
Isopropylnitrite	$(CH_3)_2 CH NO_2$	19	11.5?
Phosphorus trichloride	$P Cl_3$	22	3.36
Arsenic trichloride	$As Cl_3$	21	12.35
Antimony trichloride (s)	$Sb Cl_3$	18	5.4
Antimony trichloride (l)	$Sb Cl_3$	75	33.2
Stannic chloride	$Sn Cl_4$	22	3.2
Antimony pentachloride	$Sb Cl_5$	21.5	3.78
Sulphur monochloride	$S_2 Cl_2$	22	4.8
Sulphur trioxide (s)	$(SO_3)_2$	19	3.64
Sulphur trioxide (l)	$(SO_3)_2$	22	3.56
Sulphurylchloride	$SO_2 Cl_2$	22	9.15
Thionylchloride	$SO Cl_2$	22	9.05
Phosphorus oxychloride	$PO Cl_3$	22	13.09
Sulphur dioxide (l) [1]	SO_2	22	12.35
Bromine (l)	Br	23	3.18
Iodine (s)	I.	23	10.3?

The results obtained with the aliphatic nitriles the primary amines, and the nitrates are represented graphically in Curves I, IV and V of the accompanying figure. The dielectric constants are plotted as ordinates, and the members of the homologous series are noted as abscissæ, a definite distance being chosen for each addition of CH_2. Curve II represents Drude's[2] values for the dielectric constants of the alcohols, while curve II (a) presents approximately the values obtained by Thwing,[3] Nernst[4] and Tereschin[5] for the dielectric constants of the alcohols. Curve III represents the values obtained by Drude for the dielectric constants of the fatty acids. Hence in Curve I, R rep-

[1] Linde gives the value 14.8 at 23°. Coolidge gives the value 13.75 at 14.5.
[2] Zeit. phys. Chem. 23, 309. (1897).
[3] Zeit. phys. Chem. 14, 286, (1894).
[4] Zeit. phys. Chem. 14, 622, (1894).
[5] Wied. Ann. 36, 792, (1889).


100
90
80
70
60
50
40
30
20
10
Curve I Nitriles.
" II, IIa. Alcohols
" III Acids
" IV Amines.
" V Nitrates.
I
II
IIa
III
IV
V
H. Schlundt.
HR
CH_3R
C_2H_5R
C_3H_7R
C_4H_9R
$C_5H_{11}R$
$C_6H_{13}R$

resents the cyanogen group (CN); in Curves II and IIa, R represents the hydroxyl group (OH); in Curve III, it represents the carboxyl group (COOH); in Curve IV the amido group (NH_2); while in Curve V, R represents the (NO_3) group. The value 16.2 for the dielectric constant of liquid ammonia is taken from the work of Coolidge[1] who measured its dielectric constant at 14° C.

Discussion of Results.

The marked differences that exist between the physical properties of the first two members of any homologous series of compounds are well exemplified by the great differences between the dielectric constants of hydrocyanic acid and acetonitrile, of water and methyl alcohol and of formic acid and acetic acid. The difference in value between the dielectric constants of liquid ammonia and liquid methylamine is not so marked as in the other cases just mentioned; but it is highly probable that the value found for methylamine is too high. The curves show that in an homologous series the dielectric constants decrease with increase of molecular weight. This also holds for the aromatic amido compounds. Pyridine (D. C., 12.4) and α-picoline (D. C., 9.8) also illustrate this fact, as do also nitrobenzene [D. C., 35.0] and ortho-nitrotoluene [D. C., 27.][2] The primary amines have higher values for their dielectric constants than the corresponding secondary amines, and the values for the secondary amines are higher than the tertiary, as is shown by the following examples:

Ethylamine, D. C. = 6.17.
Diethylamine, D. C. = 3.58.
Trimethylamine, D. C. = 2.95.

A further inspection of the values of the dielectric constants of the several homologous series of liquid compounds investigated by other observers will show that a decrease in the value of the dielectric constant with increase of molecular weight is

[1] Wied. Ann. 69, 130, (1899).
[2] This value was found by Turner. Zeit, phys. Chem. 35, 385, (1900).

the general rule. Tereschin[1] first pointed out this fact in connection with the values he obtained for the dielectric constants of a number of homologous esters of the aliphatic acids and of benzoic acids. The values obtained by Tomaszewski,[2] however, for the dielectric constants of the homologues of benzene, show that their dielectric constants increase with increase of molecular weight. The dielectric constants of the homologues of benzene and a number of aliphatic hydrocarbons have been determined by Landolt and Jahn,[3] by Nernst,[4] and by others. Some of these results are given in the following table: The second column indicates the values of the dielectric constants obtained by Tomaszewski, the third column the values obtained by Landolt and Jahn, while the last column gives the values obtained by Nernst.

TABLE V.

Substance.	D. C. (Tomaszewski).	D. C. (L.&J.).	D. C. (Nernst).
Benzene	2.218	2.222	2.255
Toluene	2.303	2.387	2.355
Xylene (ortho)	.....	2.583	2.567
Xylene (meta)	.....	2.35	2.372
Xylene (para)	2.383	2.245	2.251
Mesitylene	.....	2.30	.....
Pseudocymene	.....	2.417	2.415
Cymene	2.442	2.231	2.249
Benzene	2.218	2.222	2.255
Toluene	2.303	2.387	2.355
Ethylbenzene	.....	2.414	2.424
Propylbenzene	.....	2.351	2.380
Iso-propylbenzene	.....	2.376	2.368
Iso-butylbenzene	.....	2.341	2.347
Hexane	.....	1.854	1.88
Octane	.....	1.938	1.949
Decane	.....	1.964	.....

1 Wied. Ann. **36**, p. 801, (1889).
2 Wied. Ann. **33**, p. 41, (1888).
3 Zeit. phys. Chem. **10**, 289, (1892).
4 Zeit. phys. Chem. **14**, 622, (1894).

From the results of Landolt and Jahn and those of Nernst it appears that the dielectric constants at first increase with increase of molecular weight and subsequently they decrease as the molecular weight increases. Tomaszewski's values show an increase with increase of molecular weight throughout. Regardless of which series of values for the dielectric constants is correct, the results show that these hydrocarbons do not follow the rule observed in connection with most other homologous series of compounds,—namely, that an increase in molecular weight is accompanied by a decrease in the value of the dielectric constant.

The isomeric nitriles and alcohols have nearly the same dielectric constants, the iso-compounds showing slightly higher values. With the substituted ammonias the iso-compounds examined gave lower values than the normal compounds.

A comparison of the values of the dielectric constants of the alcohols and nitriles by means of Curves I and II shows that for oscillations of high frequency the nitriles have higher values throughout than the corresponding alcohols. For oscillations of low frequency the values for the dielectric constants of the higher members of the alcohol series are nearly the same as the values found for the corresponding nitriles with high frequency oscillations. [Compare curves IIa and I.] Since the nitriles show but slight absorption, their dielectric constants when examined by other methods where slower vibrations are used will probably agree closely with the values found with Drude's apparatus.

The marked effect of the presence of the cyanogen group in a compound upon the value of its dielectric constant, is further illustrated by comparing the dielectric constants of ethylacetate ($CH_3\ COOC_2\ H_5$) and ethylcyanacetate ($CH_2\ CNCO_2\ C_2\ H_5$), for which Drude[1] found the values 5.85 and 26.7 respectively. The values 26.5 and 65.3 here found for ethylcyanide ($C_2\ H_5\ CN$), and ethylene cyanide ($C_2H_4(CN)_2$), respectively also exemplify this effect in a striking manner. Cyanogen itself,

[1] Zeit. phys. Chem. pp. 308, 310, (1897).

however, has a very low dielectric constant, the value being intermediate between the values of chlorine and bromine. The dielectric constant of liquid chlorine was determined by Linde,[1] who found the value 1.93 at 14° C., and by Coolidge[2], who obtained the value 1.87 at 14.3° The values obtained for liquid cyanogen (Table V)and bromine are 2.52 and 3.18, respectively, at 23° C.

For the purpose of this discussion, the inorganic solvents whose dielectric constants were measured, are divided into two groups. One group contains the solvents whose dielectric constants range from three to five, while the other group contains the solvents whose dielectric constants range from nine to thirty-three.

D. C. 3 – 5.	D. C. 9 – 33.
Sulphur monochloride.	Arsenic trichloride.
Phosphorus trichloride.	Antimony trichloride.
Sulphur trioxide.	Phosphorus oxychloride.
Antimony pentachloride.	Sulphur dioxide.
Stannic chloride.	Sulphuryl chloride.
Bromine.	Thionyl chloride.

The ionizing power of these solvents has been investigated by Kahlenberg and Lincoln[3], and more fully by Walden.[4] The electrical conductivity measurements of Walden show that the solvents with low dielectric constants yield solutions with tetraethylammonium iodide, which do not conduct well enough to make quantitative measurements profitable, while the other solvents with relatively higher dielectric constants yield solutions with the same salt and with other salts that conduct fairly well. (See Table II.) Here then we have a good illustration of the Nernst–Thomson rule, that the greater the dielectric constant of a solvent the greater is its dissociating power. The following

1 Wied. Ann. 56, 546, (1895).
2 Wied. Ann. 69, 123, (1899).
3 Jour. phys. Chem. 3, 12, (1899).
4 Berichte d. Deutsch. Chem. Gesel. 32, 2862, (1899). Zeit. anorg. Chem. 25, 209, (1900).

table gives the molecular conductivities at nearly corresponding dilutions of tetraethylammoniumiodide, $[N(C_2H_5)_4I]$, dissolved in the solvents noted. These results are taken from the work of Walden to which reference has already been made. The molecular conductivities in liquid SO_2 were made at zero degrees; in the other solvents the conductivities were made at 25° C. The last column indicates the dielectric constants of the solvents.

TABLE VI.

Solvent.	V.	U_V.	D. C.
$PO\,Cl_3$	500	33.45	13.9
$As\,Cl_3$	480	54.26	12.35
$SO_2\,Cl_2$	500	19.59	9.15
$SO\,Cl_2$	514	25.50	9.05
SO_2	181[1]	126.9	13.5

In connection with the results presented in this table it may be noted that there is no such parallelism between dielectric constant and molecular conductivity as one would expect by the Nernst–Thomson rule.

The high dielectric constant found for hydrocyanic acid is of special interest from a theoretical point of view since by the Nernst–Thomson rule, this compound should possess extraordinary dissociating power. The qualitative tests which Prof. Kahlenberg and I have made, however, indicate that hydrocyanic acid does not possess dissociating power in a marked degree. A number of salts which yield excellent conducting solutions when dissolved in water, show comparatively feeble conduction when dissolved in hydrocyanic acid. Here then is a striking exception to the Nernst–Thomson rule. The quantitative measurements of the electrical conductivity of salts dissolved in hydrocyanic acid are now in progress in this laboratory and their publication will doubtless be awaited with considerable interest.

[1] This is the highest dilution which Walden examined.

The high dielectric constants of the nitriles and alcohols show a marked contrast to the low dielectric constants of the substituted ammonias, which are of about the same order as the dielectric constant of chloroform [D. C. = 5.0], and ether [D. C. = 4.4]. Now the ionizing power of chloroform and ether is exceedingly small, which fact is in perfect accord with the Nernst–Thomson rule. But Prof. Kahlenberg[1] finds that the primary amines, which have values for their dielectric constants approximately the same as those of chloroform and ether, still yield solutions that conduct fairly well. Here then we have a number of exceptions to the Nernst–Thomson rule opposite in kind to the case of solutions in hydrocyanic acid; namely, solvents with relatively very low dielectric constants that still possess moderate ionizing power.

The electrical conductivity of solutions in nitriles has been studied by Dutoit and Friderich.[2] Their results show that the conductivity of salts dissolved in the homologues, acetonitrile, propionitrile, and butyronitrile decreases in the order in which the solvents are named. Their dielectric constants also decrease in the same order; thus supporting the Nernst–Thomson rule. This relation between the dielectric constant and electrical conductivity is illustrated by the following table, in which U stands for the molecular conductivity at 25° C., and V, the number of liters in which one gram molecule of silver nitrate is dissolved.

TABLE VII.

Solvent.	V.	U.	D. C. at 21°.
Acetonitrile	64.0	103.7	36.4
Propionitrile	63.7	46.0	26.5
Butyronitrile	75.6	25.4	20.3

Propionitrile and benzonitrile have about the same dielectric constant, but the molecular conductivities of silver nitrate dis-

[1] Jour. phys. Chem. June, 1901.
[2] Bull. Chem. Soc. Paris [3] 19, 321, (1898).

solved in these nitriles are quite different, as a comparison of the results in the followng table shows. The molecular conductivities of silver nitrate in benzonitrile are taken from the work of Lincoln[1] while those for the propionitrile are taken from the work of Dutoit and Friderich.[2]

TABLE VIII.

Benzonitrile.		Propionitrile.	
V.	U at 25°C.	V.	U at 25°C.
24.06	7.66	32.0	34.9
58.98	11.19	63.7	46.0
83.92	13.41		

The molecular conductivities of silver nitrate dissolved in pyridine and in butyronitrile furnish another interesting comparison.

TABLE IX.

Solvent.	V.	U. at 25°C.	D. C.
Butyronitrile [3]........................	75.6	25.4	20.3
	150.4	32.1	....
Pyridine [4]......................................	60.9	30.17	12.4
	140.7	36.21	....

While Table VII shows that the Nernst–Thomson rule holds for the three members of the same homologous series, Table VIII demonstrates that chemically analogous substances having about the same dielectric constants may nevertheless yield solutions (containing the same solute) with very different electrical conductivities. Table IX shows conclusively that a pyridine solution of silver nitrate conducts better than a corresponding

[1] l. c. pp. 422, 423.
[2] l. c. pp. 300, 331.
[3] l. c. pp. 422, 423.
[4] l. c. pp. 330, 331.

one in butyronitrile, notwithstanding the fact that the dielectric constant of pyridine is only 61% of that of butyronitrile. Here, then, we have two further exceptions to the Nernst–Thomson rule. But in these cases the exceptions might be explained on the basis of the theory of electrolytic dissociation. Since the molecular conductivity depends upon the speed of the ions as well as the number of ions, i. e., the degree of dissociation, it might be argued that the magnitude of the conductivity at corresponding dilutions, giving as it does the combined effect of these two factors, is therefore not a safe criterion for determining the dissociating power of a solvent, although comparisons of this kind are frequently made in support of the rule. For example, in the case of the molecular conductivities of silver nitrate in pyridine and butyronitrile, if it be assumed that the speed of the ions in pyridine is materially greater than in butyronitrile, then the molecular conductivity in pyridine may be greater than in butyronitrile, even though the number of dissociated molecules be somewhat less, as is required if we assume the Nernst–Thomson rule to hold. In the cases cited in Tables VIII and IX the degree of dissociation could not be computed from the electrical conductivity measurements, as no maximum value for the molecular conductivity was obtained. And since, in the case of pyridine and benzonitrile solutions, Werner[1] found normal molecular weights for silver nitrate by boiling-point determinations, this means of calculating the degree of dissociation could of course not be applied.[2] Hence on the basis of the experimental evidence which can be applied in these cases, they must be considered exceptions to the Nernst–Thomson rule.

In this connection it may be well to note a few other exceptions to the Nernst–Thomson rule. The cryoscopic and electrical conductivity measurements by Zanninovich-Tessarin[3] show that potassium chloride dissolved in formic acid is highly dissociated, as one would expect from the high dielectric constant

[1] Zeit. anorg. Chem. 15, 1, (1897).
[2] Compare Kahlenberg, Jour. Phys. Chem. 3, pp. 397-399 on this point.
[3] Zeit. phys. Chem. 19, 251, (1896).

[D. C. = 62] of the latter. But solutions of hydrochloric acid in this solvent show but slight dissociation. Nernst[1] in referring to this case assumes that some specific influence of the solvent comes into play, probably the association of the ions with the molecules of the solvent.

Another exception is noted by Franklin and Kraus[2] in their researches on the electrical conductivity of liquid ammonia solutions. Mercuric cyanide, according to Ostwald,[3] is not at all dissociated in water, but Franklin and Kraus find that in ammonia it forms a solution which possesses a distinct conductivity. Again, the phenols yield good conducting solutions in ammonia, while in water they form solutions which have relatively low conductivity. The following table illustrates this point. It gives the molecular conductivities of orthonitro-phenol in water at 18° C. and in liquid ammonia at —38° C.

TABLE X.

WATER [4])		LIQUID AMMONIA [5])	
V.	U.	V.	U.
250	4.09	366.2	82.76
500	5.14	2299.0	148.3
1000	7.24	10380.0	203.9
2000	10.30	63860.0	240.1
$U\ \infty = 355$			

Choral and ethyl acetate, according to Drude,[6] have the values 6.67 and 5.85, respectively, for their dielectric constants. The former, according to Kahlenberg and Lincoln,[7] yields solutions with ferric chloride which show no appreciable conduction, while the latter yields solutions with it, which show a distinct conductivity. From the work of the same investigators we see

[1] "Theoretische Chemie," p. 365. (Dritte Auflage).
[2] Am Chem. Journal, 23, 207, (1900).
[3] Grundlinien der anorg. Chem. p. 637.
[4] Bader: Zeit. phys. Chem. 6, p. 296, (1890).
[5] Am. Chem. Jour. 23, p. 295, (1900).
[6] Zeit. phys. Chem. 23, p. 309, (1897).
[7] Jour. Phys. Chem. 3, 12, (1899).

that ferric chloride does not yield conducting solutions with ethylene chloride [D. C. = 11.3[1]], but it yields solutions with several other solvents having dielectric constants of about the same order or even less, which have very distinct conductivity. Here, then, we have a number of additional exceptions to the Nernst–Thomson rule.

The exceptions to the Nernst–Thomson rule noted above in connection with liquid ammonia solutions, however, do not indicate the general behavior of ammonia solutions of the common salts. While it is true that ammonia solutions for the most part show greater molecular conductivity than aqueous solutions of the same concentration, yet the degree of dissociation is as a rule less than that of the corresponding aqueous solutions. This point is well illustrated by the following table taken from the work of Franklin and Kraus.[2] It shows the dilution at which dissociation reaches 90% in the two solvents.

TABLE XI.

Solute.	Water at 18°C.	Ammonia at –38°.
KI	20.0	2000
K Br	20.0	4000
KNO_3	25 0	5000
Na Br	32.0	2500
$NaNO_3$	33.0	4000
NH_4Cl	25.0	5000
$AgNO_3$	40.0	1500

Carrara's scheme for comparing the dissociating power by calculating the dilution for the same solute in which a definite degree of dissociation is obtained by electrical conductivity measurements, seems an excellent one to apply in this connection to solvents which yield good conducting solutions. In the following table the volumes of the solvents enumerated correspond to

[1] Jahn and Möller: Zeit. phys. Chem. 13, 385, (1894).
[2] Am. Chem. Jour. 23, 297, (1900).

a degree of dissociation equal to 76%, according to Carrara,[1] the solute being tri-ethylsulphine iodide, $(C_2H_5)_3$ SI. Under V the volume in liters is given in which one gram molecule of substance is dissolved. The dielectric constants in the second column are those found by Drude, while those in the third column are taken from the results of Nernst, Tereschin, and Thwing. According to the Nernst–Thomson rule the volumes should increase as the D. C. decreases.

TABLE XII.

Solvent.	D. C.	D. C.	Volume.
Water	81.0	80	8
Methyl alcohol	32.5	32.6	39.6
Ethyl alcohol	21.7	25.8	504.0
Propyl alcohol	12.3	22.8	1015.0
Allyl alcohol	20.6	21.6	89.0
Acetone	20.7	21.8	498.0

An inspection of the table shows that with one exception there is a general parallelism between dissociating power and dielectric constant, but the example of allyl alcohol is certainly a striking exception.

Table XIII gives the approximate volumes of various solvents in liters in which a gram molecule of potassium iodide is dissociated to the extent of 75%.

TABLE XIII.

Solvent.	D. C.	Volume.
Water	80.	0.4
Methyl alcohol	32.5	29
Liquid ammonia	22.0	400
Acetone	20.5	128
Pyridine	12.4	1100

In this case we have another exception in liquid ammonia and acetone.

[1] Zeit. Elektrochem. 4, 475, (1897-98).

When the exceptions noted are considered collectively it becomes evident that the Nernst-Thomson rule must relinquish a good share of the prestige it has hitherto enjoyed. While it is true that in these pages a number of new examples supporting the rule have been given, yet the exceptions noted are of a kind not to be underrated. The rule as it now stands is no more general than the hypothesis of Brühl which attempts to account for the dissociating power of solvents by assuming spare valences to exist, or the parallelism that Dutoit and Aston claim between dissociating power and polymerization of the molecules of the solvent. These theories have been shown to be inadequate by Lincoln,[1] Euler,[2] and Kahlenberg.[3] These investigators cite striking exceptions to these theories and therefore hold them untenable. Hence until we have some experimental evidence in place of the speculative "specific influences" which are said to exist and to account for exceptions to the Nernst-Thomson rule, it must be considered inadequate in accounting for the dissociating power of solvents by virtue of their high specific inductive capacity.

Relation between the dielectric constant and the latent heat of evaporation.—Since Louguinine[4] and Kahlenberg[5] have recently determined the latent heat of evaporation of a number of nitriles it seemed of interest to see how closely Obach's law, that the ratio between the dielectric constant and the latent heat of evaporation is approximately a constant for an homologous series, holds for the nitriles. The following table gives the latent heats of evaporation, the dielectric constants, and in the column headed $\frac{\text{L. H.}}{\text{D. C.}}$ the ratio of the heat of evaporation to the dielectric constant:

[1] Jour. Phys. Chem. 3, 457, (1899).
[2] Zeit. phys. Chem. 28, 619, (1899).
[3] Jour. Phys. Chem. June (1901).
[4] Compt. Rend., 132, 88, (1901).
[5] Jour. Phys. Chem. 5, 215, (1901)

TABLE XIV.

Substance.	L. H.	D. C.	L. H./D. C.
Acetonitrile	173.6	36.4	4.77
Propionitrile	134.4	26.5	5.07
Butyronitrile	115.25	20.3	5.48
Valeronitrile	95.96	17.4	5.51
Capronitrile	88.09	15.5	5.68

The ratios can hardly be said to be constant although the values obtained for the nitriles show as close an agreement as the values Obach had in hand when he indicated the relation between dielectric constant and heat of vaporization, as will appear from the following table which has been selected for comparison:[1]

TABLE XV.

Substance.	L. H.	D. C.	Ratio.
Methyl formate	105.8	9.9	10.7
Ethyl formate	91.9	9.1	10.1
Propyl formate	83.7	9.0	9.3
Iso-butyl formate	75.7	8.4	9.0
Amyl formate (iso)	71.0	7.7	9.2

Conclusion.

The principal points in the foregoing presentation may be summarized in the following general statements:

1. The values of the dielectric constants for the homologous series of compounds examined decrease with increase of molecular weight.

2. The introduction of the cyanogen group in a compound causes a marked increase in the value of the dielectric constant. In this respect the cyanogen radical produces a greater effect than all other radicals which have hitherto been systematically studied.

[1] Phil. Mag. 32, p. 117, (1891).

3. The cyanogen (CN), amido $(NH)_2$, or nitric acid (NO_3) radicals when present in compounds do not cause anomalous absorption as Drude found for the hydroxyl (OH) group.

4. A number of new examples have been given which follow the Nernst–Thomson rule.

5. Some striking exceptions to the Nernst–Thomson rule have been pointed out from which it has been argued that the rule is inadequate. The exceptions indicate that the nature of the solvent as well as the dissolved substance are of prime importance in determining whether a solution will conduct electricity.

6. Obach's law holds only approximately for the nitriles.

This investigation was made in the Laboratory of Physical Chemistry of the University of Wisconsin. It was undertaken at the suggestion of Professor Kahlenberg and carried on under his supervision. As before stated, I am indebted to him for placing at my disposal many of the solvents used for these measurements, and I am under many obligations to him for his helpful suggestions and for the active interest he has always shown in my work; and I am glad to have this opportunity of acknowledging it.

A portion of the results of the work on the nitriles has previously been published in a preliminary article in the Journal of Physical Chemistry **5**, 157, (1901). For the sake of completeness the results have also been incorporated in the present paper.

Laboratory of Physical Chemistry,
University of Wisconsin,
Madison, May, 1901.

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